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THE TWO-CYLINDER COMPOUND ENGINE IN WHICH THE STROKES ARE SIMULTANEOUS, OR CO-INITIAL AND CO-TERMINAL, WITH RECEIVER, CUSHION, CLEARANCE, ETC.

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II.

COMPOUND PUMPING ENGINES.

In rotative compound pumping engines any of the foregoing cases will apply as well as for other purposes. But for non-rotative pumping engines some difficulty is experienced in maintaining motion near the end of the stroke, due to the fall of pressure of the expanding steam.

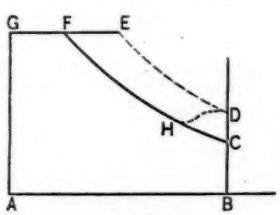


FIG. 11.

To admit a puff of steam near the end of stroke for a last lift that shall carry the engine over is very wasteful of steam. To illustrate by a diagram, suppose the expansion be carried from F to H, Fig. 11, at which latter point the engine falters. Now to admit a portion of steam that shall cause the pressure to rise to D, and add the area HDC over what it would have been without the added steam; the effect is a loss of work from what it would have been had the same steam been admitted at the beginning of the stroke as represented by the area HFEDH, and the expenditure of steam is increased by the ratio EG÷FG. (This estimate, however, will be slightly modified by the fact that the steam thus admitted is reduced in pressure at the admission and superheated somewhat.)

Owing to this difficulty it is customary to use no cut-offs on the cylinders, but to secure the expansion by passing the steam from the high-pressure into the low-pressure cylinder.

If there be no receiver the diagram is of the kind shown in Fig. 9, and the work performed per stroke is given by equation (12) for $r_1=1$. An example of such an engine is shown in Fig. 1, though the intermediate steam pipe must have the effect of a receiver in small degree.

If there be a receiver and no cut-offs, the diagram is shown in Fig. 4. In practice the communicating passage between the cylinders amounts to a small

receiver in effect, however small it may be, and the expression of amount of work per stroke is given in (14). The receiver has the effect to reduce the work per stroke by the ratio, see Fig. 4,

$$\frac{QFLINOQ}{QFLKNOQ} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (29)$$

if there be no reheating in the receiver. But in reheating great advantages may arise, as already considered.

The Tank Engine.*

An interesting form of compound engine for pumping has been introduced to some extent by H. R. Worthington, and by Cope and Maxwell, in which there are two cylinders, one larger than the other, and an intermediate "tank" or receiver.

The high-pressure cylinder in this engine is supposed to take its steam at constant pressure from a boiler during its full stroke, then to exhaust into the receiver. The back pressure is the pressure of the steam in the receiver, which will be somewhat variable according to relation of sizes of receiver and cylinders. The low-pressure cylinder steam supply will also vary somewhat in pressure according to pressure in the receiver. This cylinder exhausts into the air, or into a condenser; the back pressure due to which is assumed constant in the calculations.

As to the piston movements three are possible, viz., 1st, they may have entire independence; 2d, they may be limited to an equal number of strokes per minute, with initial points in certain relation; and, 3d, they may be further limited by periods of tarrying. The latter is the case with the engine now considered.

As to the valve movements, four are possible, each differing from another in efficiency of the engine. Two are selected as special objects for investigation here, viz., the one with the lowest efficiency, and that with the highest. But all these efficiencies approach, and, finally, have a common value as the receiver is enlarged to infinity. For this latter and special case the formulas are much simplified.

One important fact to be pointed out is that with a certain mode of working the valves, a comparatively small receiver gives a higher efficiency of steam than a larger, or infinite one.

The engine, with two pistons and one receiver, is briefly shown by diagram in Fig. 12, where b, d, are admission valves

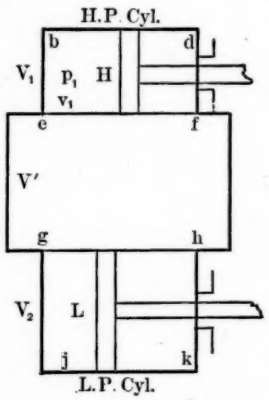


Fig. 12.

for high steam, into small cylinder e, f, exhaust valves from the small cylinder into the receiver; g, h, admission valves from the receiver to the low-pressure cylinder; and j, k, exhaust valves from the low cylinder.

The action of the pistons, except where mentioned as otherwise, is considered as alternating; that is to say, one piston stands still at the end of the cylinder, while the other makes its stroke, and conversely. This is the third above mentioned.

The diagram will enable us to indicate the fact of different ways for working the valves. For instance: 1st, suppose b and f open, e and d closed, piston H moving, and piston L standing at end of cylinder. Then with j and k closed, g and h may be either opened or closed. If closed, the steam from f accumulates only in the receiver, while if open, it flows into both the receiver and L cylinder. This option in the valves g and h occasions two valve movements. Again: 2d, suppose piston L moving, while piston H stands at the end of the stroke, then with b and d closed, e and f may be either opened or closed, a second option which occasions two separate valve movements,

* Extracted from a paper read before the American Society of Mechanical Engineers.

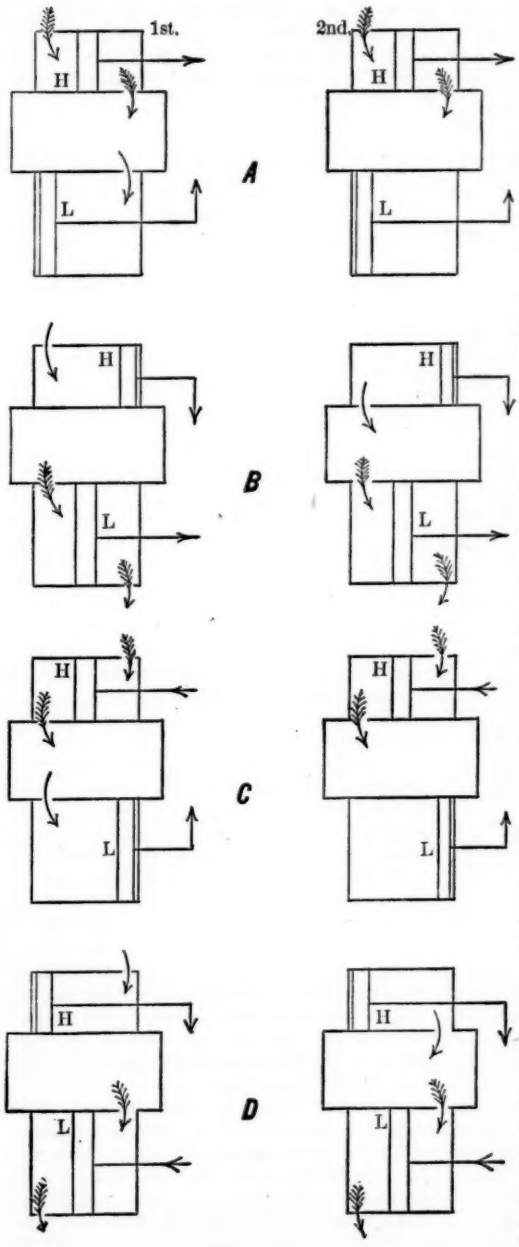


FIG. 13.

for this side of the engine. In the combined action of both sides, it appears from the fact that these options are independent of each other, there results four possible valve movements, two of which, as above mentioned, are selected for investigation and comparison, and are shown in Fig. 13. The 1st is the least, and the 2d the most efficient of the four.

In the 1st, and also 2d, of Fig. 13, the engine is represented in the four relations necessarily undergone for the completing a cycle of operations. For instance in 1st, we have piston H moving while piston L stands, then H stands while L moves, next H moves opposite to the first as L stands, and finally H stands as L moves, contrawise to that of its first stroke. The next move is the same as the first, and thus they continue in repetition. Piston-rods are shown by arrows, which indicate direction of motion. Broken arrows mean standing still.

In Fig. 13 all open valves are indicated by arrows. Feathered arrows are put for valves necessarily open, while naked arrows are at valves in option. In the light of these remarks, the valve movements of 1st and 2d may be traced throughout, also steam action. For convenience let the four relations of Fig. 13 be designated as A, B, C, and D, as shown.

Then in 1st: for the A relation we have H moving with high steam on one side and exhaust on the other. These are necessary conditions while H moves, and hence the arrows are feathered. The exhaust, however, is shown as into the receiver not only, but the L cylinder as well, because the valve to the L cylinder is open. But that valve might be closed when the steam would be confined to the receiver with a more rapid rise of pressure. The

latter condition is shown in the A relation of 2d, hence this arrow is left naked.

Again in the B relation, the H piston is standing while L is making its stroke. The valve between H and the receiver is closed in 1st, or it may be open as in 2d, and hence the arrow is featherless, as shown.

These references suffice to explain the C and D relations also.

V. Solution for the First Valve Movement of Fig. 13.

Before making statements of steam action it will be necessary to know specifically the condition of the steam at every point as it passes through the engine. For the 1st part of Fig. 13, the complete diagram of steam action, for continuity of engine movement, is given in Fig. 14.

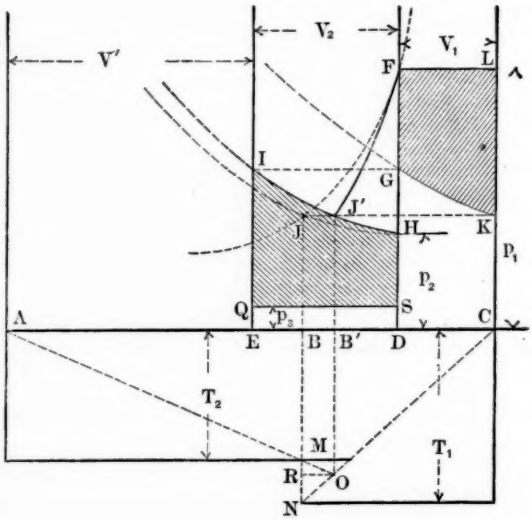


Fig. 14.

Let V_1=volume of the high pressure cylinder, V_2=volume of the low-pressure cylinder, and V'=volume of the receiver. These volumes are shown on the diagram in their proper relations. Also the absolute pressures P_1 of the boiler, P_2 of terminal expansion, and P_3 of the exhaust, are shown. Other pressures will be indicated according to lettering of diagram, as, for instance, $P_i = P_g$ being the pressures at the points I and G. In short, the pressures and volumes are represented by vertical and horizontal distances respectively, with A for the zero or origin.

The Complete Diagram and Indicator Cards.—Now, referring to 1st of Fig. 13, we see that in the A relation the low-pressure or L-piston is standing at the end of its stroke, and with the valve between that cylinder and the receiver open; the steam that made the last L-stroke being retained. Hence the L-cylinder and receiver both together are serving as receiver, while the high-pressure or H-piston is making its stroke and forcing the steam from the H-cylinder into the receiver. The H-piston is moved by steam from the boiler, the same being admitted at full pressure P_1, and full stroke.

Now in Fig. 14, FL represents this high-pressure line of P_1, while KG represents the compression line of the H-piston stroke. It is to be observed that at the initial return of H, the volume is $AC=V_1+V_2+V'$; and at the end, it is $AD=V_2+V'$.

Next, in the B-relation of 1st of Fig. 13, the valves of L are reversed, as H

completes its stroke, the steam in the L-cylinder being exhausted. In Fig. 14 this exhaust is shown by a cutting off of the steam GI, and leaving only that in the receiver, of volume $V'=AE$, to act upon the L-piston.

The H-piston now stands while the L-piston makes its stroke with a change of active steam volume from V' to $V'+V_2$; and producing the expansion line IH, Fig. 14. Next the valves of L, Fig. 13, remain, while the valves of H reverse; so that the L-piston stands while the H-piston moves as in the C movement.

Now as the valves of H reverse, the high steam exhausts into the receiver and L-cylinder together, giving the expansion line FJ for the high steam, and the compression line HJ for the low steam, till both arrive at a common pressure at J. The expansion line FJ is to be drawn with C as the point of zero volumes and pressures; while HJ has A for the like point. Here the steam, isodynamically brought down from P_1 at F, will be hotter than that brought up from P_2 at H; and as they commingle, the volume JK decreases by giving up heat, and the volume AB increases by receiving that heat. But as the same weight of steam must necessarily be exhausted from the high cylinder as from the low at a stroke, it follows that the steam JK introduced must have equal weight with the steam GI exhausted. Hence the volume JK must shrink by cooling to some volume J'K, such that J' lies on the expansion curve IH; because when AC is compressed along KG to AD, then J'K must compress to GI, and AB' to AE. The curves KG and J'I are of like sort, with the point A for the zero of pressures and volumes.

Now H commences its stroke with a back pressure $P_3=CK$, and the volume $AC=V_1+V_2+V'$. At the end of the stroke, this volume has been reduced to AD, giving the compression line KG. At the end of this stroke the valves of L are reversed, causing the immediate exhaust from L of the volume $GI=V_2$, when in the L-stroke the expansion curve IH, etc., is formed as before.

Thus it appears that FGKL is the indicator card of the H-cylinder, while HIQS is the card for the L-cylinder. The work done by these cylinders will be proportional to these areas. The back pressure is $EQ=P_3$.

Nature of the Expansion and Compression Lines.—Having traced out the action of the engine and of the steam as it is worked in it, we are prepared to inquire into the specific nature of the various lines of the complete diagram, Fig. 14, from the standpoint of thermodynamics. Thus the compression curve KG is adiabatic, and such that if the steam is saturated at K, it is superheated at G by the compression. Hence, as the steam will be shown to be not far from saturated at K, this curve is an adiabatic for superheated steam. The same is true of J'I, because as K is compressed to G, J' is compressed to I. After the exhaustion of the volume GI, the curve IJ' is retraced by expansion with the same steam as was just compressed along J'I. But with J'H the case is to some extent different, before explaining which, we must consider JH and JF. With respect to the latter, it is to be observed that at the end of the stroke of the L-piston, the volume $V'+V_2$ is ready to receive the high steam exhaust from the H-cylinder. Here the low-steam pressure is $DH=P_2$, and high-steam pressure $DF=P_1$; while the volumes are $V'+V_2=AD$, and $V_1=DC$, respectively. Now as the valve from H to the receiver opens, these two portions of steam coalesce * into a common body, whose volume is simply the sum of the previous partial volumes; that is to say,

$$(V_2+V')+V_1=V_1+V_2+V';$$

and the resulting pressure is BJ. In this act no exterior work is performed by the mass of steam in the volume AC, because, for the instant during which this commingling occurs, the pistons of the engine do not move perceptibly. This act is therefore governed by *Hirn's law*; that is to say, because no external work is done during the change, the internal energy of the mass of steam remains constant. The curve representing this action is the so-called *isodynamic curve*. Hence the pressure BJ is to be found at the inter-

* This, however, is only partially true, since some of the steam remains in the *H*-cylinder till forced out through the open valve into the receiver during the return stroke. Though the pressure is common, yet the temperature and density of that remaining in the cylinder will probably differ somewhat from that in the receiver.

section of two isodynamic lines FJ and HJ; the first representing the isodynamic expansion of the volume V_1, and the second, the compression of the volume $V' + V_2$.

Though these curves serve to determine the point J, or resulting pressure BJ, yet it is to be understood that they do not represent the operations which actually take place in the two portions of steam, because the low steam is in reality compressed adiabatically from H to J', and the work B'DHJ' performed. This work is performed by the expansive action of the high steam while actually expanding along some line FJ' and not FJ. This curve, however, will lie above the adiabatic through F, because in expanding along FJ' the steam is not doing its full work, the work actually done being only B'DHJ' instead of an area extending fully up to the expansion line. Hence, J' instead of J, represents the actual resulting point of pressure.

Now the points J and J' are expected to be *very nearly* in a horizontal line, but may not be exactly so for several practical reasons. The expansion J' H will probably be mostly adiabatic below the saturation point, the point of change from superheat to supersaturation lying somewhere on J'H, but not far from J'. Much of the supersaturation moisture due to this expansion may be precipitated while the L-piston tarries at the end of its stroke, so that the compression heat of HJ' acts at a disadvantage in re-evaporating that moisture. The moisture thus precipitated may accumulate in the receiver as water, and require to be drawn off by a cock. To show that at the end of the stroke IH the steam is necessarily below the saturation point, we observe that KG and J'I are counter actions which offset each other, as already explained, and hence have no influence on the final condition of saturation. Now, referring to the isodynamic lines, the expansion FJ gives rise to superheat, while the compression HJ occasions condensation. These actions nearly compensate each other, because, though the intensity for FJ is greater than for HJ, yet the quantity of steam concerned in JH is greater : assuming that these exactly neutralize, then the saturation point lies very near to J', and below it if supersaturation moisture is precipitated in the receiver.

It appears, therefore, that the expansion line IH is of two kinds, viz., from I to some point near J' it is adiabatic for superheated steam, while from the latter point to H it is adiabatic for supersaturated steam.

To account for JJ' on the Supposition of Heat.—In this case the drawing-board may be preferred. Use temperatures and a diagram, as shown in the lower part of Fig. 14. As the temperatures for the isodynamic lines through J are each nearly constant, let the absolute temperatures τ_1 and τ_2 of the steam at admission and at the end of J'H be laid off downward, as shown. Draw lines to M and N, meeting JMN. Then draw straight lines AMO and CNO, giving the intersection O. Then the line through O parallel to NJ should give the point J'. The diagram ANC depends upon the law of Gay Lussac, relating to volume and temperature, for constant pressures in gases, viz., by symbols

$$\frac{v}{\tau} = \frac{v'}{\tau'}$$

In superheated steam this very nearly holds true. In the diagram the application is AB : BM : : RO : RM, and CB : BN : : RO : RN. The two portions of steam are first supposed reduced to the common pressure P_j, by the isodynamic or nearly constant temperature expansion FJ, and the like compression HJ. The volume BC then has the temperature τ_1 of P_1, and the volume AB the temperature τ_2 of p_2. The change JJ' is that by which the portion BC shrinks, and of AB expands, while the temperatures τ_1 and τ_2 merge into one temperature, $\tau_j =$ BR.

Repeated trials should be made until JJ' is a horizontal line from the intersections J of the isodynamics to the adibiatic IH, and with J'K and GI also horizontal.

But as the correction to the volume AB $= V_j$ is usually less than one per cent., it is probable that the discrepancies in results of efficiency or duty of engine due to it will be too small to merit serious consideration.

Hence, in the following general equations the points J and J' will be regarded

as coincident; and the entire expansion line IH will be treated as of one form, or as characterized by one value of the exponent x in Eq. (1).

Area of the Indicator cards; and General Equations,—To find the area of the diagram, we have from equation (6) and Fig. 14, observing that the rectangle of the pressure and volume of the initial point of the curve GK is AD×DG, and that the ratio of expansion is AC÷AD,

area GDCK=

$$P_g\frac{V_2+V'}{a-1}\left\{1-\frac{1}{\left(1+\frac{V_1}{V_2+V'}\right)^{a-1}}\right\}$$

$$=P_g V_1 M \quad . \quad . \quad . \quad (30)$$

if

$$M=\frac{V_2+V'}{V_1(a-1)}\left\{1-\frac{1}{\left(1+\frac{V_1}{V_2+V'}\right)^{a-1}}\right\} \quad (31)$$

For the particular case $a=1$, the integral becomes, for the small cylinder

$$\left.\begin{aligned}(GDCK)_{a=1}&=AP_gL_1\text{hyp.log.}\left(1+\frac{l}{L_1}\right)\\&=P_g(V_2+V')\text{hyp. log.}\left(1+\frac{V_1}{V_2+V'}\right)\end{aligned}\right\} \quad (32)$$

In these equations P_g is the absolute pressure DG, =EI.

Similarly for the area IEDH, taking the point A, Fig. 14, as the zero of volumes, we have by aid of (6)

$$IEDH=P_g\frac{V'}{a-1}\left\{1-\frac{1}{\left(1+\frac{V_2}{V'}\right)^{a-1}}\right\}$$

$$=P_gV_2N \quad . \quad . \quad . \quad (33)$$

if

$$N=\frac{V'}{V_2(a-1)}\left\{1-\frac{1}{\left(1+\frac{V_2}{V'}\right)^{a-1}}\right\} \quad . \quad . \quad (34)$$

For $a=1$, we have

$$(IEDH)_{a=1}=P_gV'\text{ hyp. log.}\left(1+\frac{V_2}{V'}\right).$$

Now the work done in the high-pressure cylinder, per stroke, is

$$P_1V_1-GDCK.$$

Also in the low-pressure cylinder it is

$$IEDH-P_3V_2.$$

Hence, when the engine is working in continuity under the first valve movement of Fig. 13, and giving the diagram of Fig. 14, then, for one stroke of each piston in regular order of continuity, the same being the half of a complete cycle of operations detailed in Fig. 13, or, for each high-pressure cylinder full of steam, the work done per stroke of both cylinders is U=(P,V,−GDCK)+(IEDH−(P, V,)

$$U=P_1V_1-P_g V_1M-P_3V_2+P_g V_2N\ (35_3)$$

all being in known terms except P_g. Fig. 14 shows that this depends on many things, and that it is in no case, in itself, arbitrary, but that, in an actual engine it is self-adjusting according to pressure of admission, dimensions of cylinders and receiver, mode of valve action, and laws of expansion.

To express P_g in convenient terms, we may write from Fig. 14, and by aid of (1) and the following table, regarding J and J′ as coincident,

$$\frac{P_1}{P_j}=\left(\frac{JK}{FL}\right)^n=\left(\frac{JK}{V_1}\right)^n.$$

Also,

$$\frac{P_i}{P_j}=\frac{P_g}{P_k}=\frac{P_g}{P_j}=\left(\frac{AC}{AD}\right)^a$$

$$=\left(\frac{V_1+V_2+V'}{V_2+V'}\right)^a=\left(1+\frac{V_1}{V_2+V'}\right)^a$$

Again, from the fact that the intercepts on horizontal lines lying between two curves constructed from (1) with one value for x and different values of P_1V_1, are proportional to the abscissas to the intersection points of the horizontal lines with either curve, we may write,

$$\frac{JK}{GI}=\frac{JK}{V_2}=\frac{AC}{AD}=\frac{V_1+V_2+V'}{V_2+V'}$$

$$=1+\frac{V_1}{V_2+V'}.$$

Eliminating JK and combining, we get

$$\frac{P_g}{P_j}\cdot\frac{P_j}{P_1}=\frac{P_g}{P_1}$$

$$=\left(1+\frac{V_1}{V_2+V'}\right)^a\cdot\left(\frac{V_1}{V_2}\right)^n\cdot\left(1+\frac{V_1}{V_2+V'}\right)^{-n}$$

$$=\left(\frac{V_1}{V_2}\right)^n\cdot\left(1+\frac{V_1}{V_2+V'}\right)^{a-n} \quad . \quad . \quad . \quad (36)$$

Eliminating $\frac{P_g}{P_1}$ by aid of (36), we find for the work of the half cycle, or for one

stroke each of the two cylinders in continuity,

$$U=P_1V_1\left\{1+\left(\frac{V_1}{V_2}\right)^n\cdot\left(1+\frac{V_1}{V_2+V'}\right)^{a-n}\cdot\left(\frac{V_2}{V_1}N-M\right)-\frac{P_2V_2}{P_1V_1}\right\} \quad . \quad . \quad . \quad (37)$$

and for the hyperbolic expansion, where a and $n=1$, we have

$$U'=P_1V_1\left\{\begin{matrix}1-\frac{V_2+V'}{V_2}\text{hyp.log.}\left(1+\frac{V_1}{V_2+V'}\right)\\-\frac{P_2V_2}{P_1V_1}+\frac{V'}{V_2}\text{hyp.log.}\left(1+\frac{V_2}{V'}\right)\end{matrix}\right\} \quad (38)$$

all quantities being in known terms. If $a=n$, the term $\left(1+\frac{V_1}{V_2+V'}\right)$ drops from (37).

If $V'=\infty$, and a and n as in (37), we get

$$U'=P_1V_1\left\{1-\left(\frac{V_1}{V_2}\right)^n\cdot+\left(\frac{V_1}{V_2}\right)^{n-1}-\frac{P_2V_2}{P_1V_1}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (39)$$

If $V'=\infty$, and a and $n=1$, we get

$$U''=P_1V_1\left(2-\frac{V_1}{V_2}-\frac{P_2V_2}{P_1V_1}\right) \quad . \quad . \quad (40)$$

In these expressions,

P_1=absolute pressure of admission, lbs. per square foot=144 (p_1'+14.7), for p_1'=lbs. per square inch of boiler pressure.

P_2=absolute back pressure to low-pressure cylinder lbs. per square foot of the atmosphere for exhausting into air, or of the condenser for condensing engines.

V_1=volume of high-pressure cylinder in cubic feet.

V_2=volume of low-pressure cylinder in cubic feet.

V'=volume of receiver and connecting pipes in cubic feet.

M and N being given by equations (31) and (34).

These equations are useful in calculating the amount of work that can be done by an engine, or in calculations for duty.

In practice any one of these equations can be used according to accuracy required, (37) being necessary for the greatest degree of exactness. It is seen, however, by (1) and the accompanying table that a much wider departure from truth results when $a=1$ than when $n=1$. When the steam is very wet the actual value of a will be much nearer unity than for dry steam. In such case some value of m should be used in place of a. Fig. 14, also, will indicate in some degree to what extent, in any practical case, we jeopardize the result by taking V' infinite in the calculations.

Pressure at Different Points of Steam Action.—It is often desirable to know the pressure at different points of the steam action in the engine. To this end we have (36) for the terminal pressure, p_g, in the high cylinder, and initial pressure in the low cylinder. This shows that if $a=n$ it matters not with p_g whether $V'=\infty$ or not. From this it appears that for $a=n$ the smaller we make V' the greater is the proportion of work done by the small and less by the large cylinder.

For the initial and final pressures in the low-pressure cylinder we have the relation

$$\frac{P_g}{P_2}=\left(\frac{V_2+V'}{V'}\right)^a=\left(1+\frac{V_2}{V'}\right)^a \quad . \quad . \quad (41)$$

combining with (36)

$$\frac{P_2}{P_1}=\left(\frac{V'}{V_2+V'}\right)^a\cdot\left(\frac{V_1}{V_2}\right)^n\cdot\left(1+\frac{V_1}{V_2+V'}\right)^{a-n} \quad . \quad (42)$$

The 4th equation preceding (36), combined with the 2d, gives

$$\frac{P_1}{P_k}=\frac{P_1}{P_j}=\left(\frac{V_2}{V'}\right)^n\cdot\left(1+\frac{V_1}{V_2+V'}\right)^n \quad . \quad . \quad (43)$$

These equations show that for $V'=\infty$ we have

$$\frac{P_g \text{ or } P_j \text{ or } P_2}{P_1}=\left(\frac{V_1}{V_2}\right)^n \quad . \quad . \quad (44)$$

which is the constant pressure of the infinite receiver, and toward which this pressure approximates as V' is made large.

Equation (36) shows that if $a=n$, as it will very nearly for wet steam, the pressure at G or I, $=P_g$, will be entirely independent of V' whether infinite or finite. The effect of this on the diagram is that the lines GK, or IH, swing around the points G and I as pivots, becoming flatter as V' is enlarged, or steeper as it is diminished. Hence, as V' is enlarged,

the work produced in V_1 decreases, while in V_2 it increases. Considering these variations, a look at the diagram, Fig. 14, shows that the efficiency of this engine increases with V′, and is a maximum when V′ is infinite.

When $V'=0$, V_2 does no work, and the engine does worse than a non-compound, but equals it when IQSH=GSS′K.

Relative Areas of Indicator Cards.—It is also desirable to know the relation between the work developed in the high-pressure cylinder and the low. From the expressions (35) and (36) given above, we readily find,

$$\frac{\text{Wk. H.-Cyl.}}{\text{Wk. L.-Cyl.}} = \frac{1-M\left(\frac{V_1}{V_2}\right)^n\left(1+\frac{V_1}{V_2+V'}\right)^{a-n}}{N\frac{V_2}{V_1}\left(\frac{V_1}{V_2}\right)^n\left(1+\frac{V_1}{V_2+V'}\right)^{a-n}-\frac{P_2V_2}{P_1V_1}} \quad . \quad (45)$$

For the hyperbolic expansion this ratio is

$$= \frac{1-\frac{V_2+V'}{V_2}\text{hyp. log}\left(1+\frac{V_1}{V_2+V'}\right)}{\frac{V_1}{V_2}\text{hyp. log.}\left(1+\frac{V_2}{V'}\right)-\frac{P_2V_2}{P_1V_1}} \quad . \quad (46)$$

If $V'=\infty$, and a and n are as in (45)

$$= \frac{1-\left(\frac{V_1}{V_2}\right)^n}{\left(\frac{V_1}{V_2}\right)^{n-1}-\frac{P_2V_2}{P_1V_1}} \quad . \quad . \quad . \quad . \quad (47)$$

If $V_1=\infty$ and a and $n=1$

$$= \frac{1-\frac{V_1}{V_2}}{1-\frac{P_2V_2}{P_1V_1}} \quad . \quad . \quad . \quad . \quad . \quad (48)$$

Heat for Producing the Steam.—The total heat consumed per high-pressure cylinder full of steam in dynamical value, or ft.-lb. units, is, see equation (2),

$$H=V_1D_1[H_1+J(t_f-32°)] \quad (49)$$

and the efficiency is given by (3).

Maximum Efficiency.—In the compound engine now considered, if the two cylinders are of nearly equal size, one does almost no work, with slight expansion, and with a corresponding low efficiency. On the other hand, if there be a very great disparity of cylinder sizes, the low-pressure cylinder may exhaust the steam so rapidly from the receiver as to carry its pressure as low or even lower than the back pressure. At the limit of equal back and receiver pressure, no work will be done by the low-pressure cylinder, and the high-pressure cylinder exhausts, in effect, into the back pressure direct. Here again we have no working expansion, and a correspondingly low efficiency. It is evident that between these limits there exists a relation of sizes which will give a maximum of efficiency.

To determine this relation, assume a fixed volume of V_1 and of V′, while V_2 is made to vary. In this way the quantity of steam used per stroke is invariable, so that the denominator of (3) is constant.

Hence, for the maximum of (3), we have only to examine the numerator, or to examine (37), (38), or (29), etc., according to contemplated accuracy. This could be done by working out several values from which to construct a curve, the maximum ordinate of which corresponds to the maximum sought. This plan is probably advisable for (37) and (38).

If we place the differential co-efficient of U″ with respect to V_2 from (39) equal zero, we get after reduction, for the case $V'=\infty$,

$$\frac{P_2}{P_1}=\left(\frac{V_1}{V_2}\right)^n\cdot\left(n\left(\frac{V_1}{V_2}\right)-(n-1)\right) \quad . \quad (50)$$

an equation which is irresolvable for the desired quantity, viz., $\frac{V_1}{V_2}$. But for a series of assumed values of $\frac{V_1}{V_2}$ the corresponding values of $\frac{P_2}{P_1}$ may be computed and tabulated. A sufficiently extended table would answer all cases, requiring conditions for the maximum efficiency.

If $n=1$, then (50) reduces to

$$\frac{P_2}{P_1}=\left(\frac{V_1}{V_2}\right)^2 \quad . \quad . \quad . \quad (51)$$

Eliminating $\frac{P_2}{P_1}$ between (50) and (39) we find the maximum of U″, or for the infinite receiver, with n as in (39);

$$U''_{max.}=P_1V_1\left\{1-\left(\frac{V_1}{V_2}\right)^n\left(1+n-n\frac{V_2}{V_1}\right)\right\} \quad . \quad . \quad . \quad . \quad . \quad (52)$$

From this, for $n=1$, or for (51) in (40) we obtain for $V'=\infty$ and $n=1$ the maximum of U'''

$$U'''_{max.}=2P_1V_1\left(1-\frac{V_1}{V_2}\right)$$

$$=2P_1V_1\left(1-\left(\frac{P_1}{P_2}\right)^{\frac{1}{2}}\right) \quad . \quad . \quad (53)$$

Conditions for Equal Work of Cylinders.—In practice it is probably desirable that the cylinders do equal work, particularly so in the Worthington pumping engine, where the especially important point is made of destroying the "water hammer" in connection with the water valve action, and of maintaining perfect uniformity of pressure and motion of the traveling water column.

To obtain an equation which shall express the conditions necessary for such equality of work of the two cylinders, we have only to place the numerator and denominator of (45) equal to each other, which becomes

$$\frac{P_2V_2}{P_1V_1}=\left(M+N\frac{V_2}{V_1}\right)\left(\frac{V_1}{V_2}\right)^n\left(1+\frac{V_1}{V_2+V'}\right)^{a-n}-1$$

$$. \quad . \quad . \quad . \quad (54)$$

In using this equation it will be necessary to assume a set of volumes and find the ratio $\frac{P_2}{P_1}$, a satisfactory value for which may require several trials.

If $V'=\infty$ (54) reduces to

$$\frac{P_2V_2}{P_1V_1}=\left(1+\frac{V_2}{V_1}\right)\left(\frac{V_1}{V_2}\right)^n-1 \quad . \quad . \quad (55)$$

If $n=1$, also,

$$\frac{P_2}{P_1}=\left(\frac{V_1}{V_2}\right)^2 \quad . \quad . \quad . \quad (56)$$

This last is the same as (51), which gives the condition for a maximum efficiency. Hence, for the case that the receiver has an infinite volume, and $n=1$, the engine works with its maximum efficiency when the cylinders do equal portions of the work. When the receiver is eight or ten times as large as the low-pressure cylinder, this engine, with its valves, working as stated, is not far from working with its maximum efficiency.

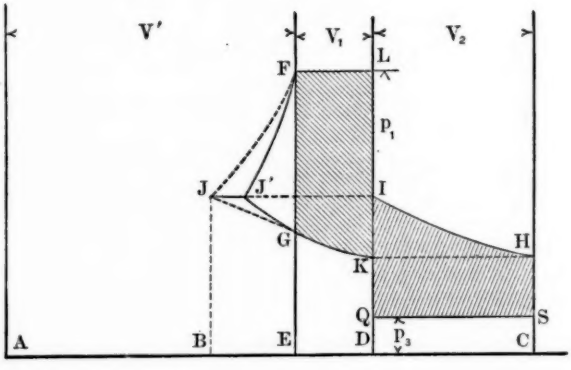


FIG. 15.

VI. SOLUTION FOR THE SECOND VALVE MOVEMENT OF FIG. 13.

The complete diagram of steam action in continuity for this case is shown in Fig. 15. The notation is as before, AC being the volume of the three parts V_1, V_2, and V'.

The piston motions are the same here as shown in Fig. 13, and, indeed, the same as in V. The sole cause for the difference in diagrams is in the valve movement, as indicated in the second part of Fig. 13.

The Complete Diagram and Indicator Cards.—When the H-piston has completed its forward stroke, all under the full boiler pressure P_1, the boiler steam is to be immediately cut off, and to be exhausted into the receiver. The resulting pressure is $BJ=DI=P_j$ The valve remains open, and ths H-piston stands,

while the L-piston makes its stroke. The latter starts while the volume of active steam is that in the receiver and H-cylinder together, and equals $AD=V_1+V'$. Hence, the expansion line for this stroke is IH, drawn with the point A for the zero of volumes. Immediately on completing the stroke, the admission valve from the receiver is closed, retaining the steam in the L-cylinder while its piston stands. Consequently the H-piston starts its stroke with a back pressure $DK=CH$ of the terminal stroke of the L-piston. The volume subject to this back pressure is AD at the start of the H piston, but during this stroke it is compressed to AE, giving the compression line KG. Then the valve immediately opens, as explained, to release the high steam which made this stroke. This steam expands against that in the receiver, which was compressed on the back stroke, giving the actual compression curve GJ′ and expansion curve FJ′; the pressures EG and EF meeting in a common pressure at J′. Then the L-cylinder starts again on the curve IH, while the H-piston stands, and so on in repetition.

The valve movement is thus seen to be peculiar. Here, instead of the valves of one cylinder all moving simultaneously, and so with the other cylinder, they move in alternation. This will complicate the valve-gear somewhat.

It is to be observed that by this arrangement, the high steam is at once released from the H-cylinder on completion of stroke, so that it is available to the L-cylinder. Also, in the L-cylinder, the steam is retained while that piston stands, instead of being at once exhausted; the object being to keep this cylinder hot as possible.

Nature of the Expansion and Compression Lines.—The point of zero of volumes for the curves HI and KGJ′ or J, is A, Fig. 15, while for FJ, or FJ′, it is D The back pressure line of the L-cylinder is QS.

Area of Diagrams and General Equations.—By aid of (7) and Fig. 15 we are able to write out

$$\text{Area GEDK}=P_k\frac{V_1+V'}{a-1}\left\{\left(1+\frac{V_1}{V'}\right)^{a-1}-1\right\}$$
$$=P_kV_1Q \quad . \quad . \quad . \quad (57)$$

if

$$Q=\frac{V_1+V'}{V_1(a-1)}\left\{\left(1+\frac{V_1}{V'}\right)^{a-1}-1\right\} \quad . \quad (58)$$

and

$$IDCH=P_k\frac{V_1+V_2+V'}{a-1}\left\{\left(1+\frac{V_2}{V_1+V'}\right)^{a-1}-1\right\}$$
$$=P_kV_2S \quad . \quad . \quad . \quad (59)$$

if

$$S=\frac{V_1+V_2+V'}{V_2(a-1)}\left\{\left(1+\frac{V_2}{V_1+V'}\right)^{a-1}-1\right\} \quad (60)$$

For the particular case that $a=1$, we have

$$(GEDK)_{a=1}=P_k(V_1+V')\text{hyp.log.}\left(1+\frac{V_1}{V'}\right)$$
$$. \quad . \quad . \quad (61)$$

and

$$(IDCH)_{a=1}$$
$$=P_k(V_1+V_2+V')\text{hyp.log.}\left(1+\frac{V_2}{V_1+V'}\right) \quad (62)$$

in all of which P_k=the pressure $DK=CH$.

Now the work done in the high-pressure cylinder will be

$$FGKL=P_1V_1-GEDK \quad . \quad . \quad (63)$$

and in the low-pressure cylinder it will be

$$IQSH=IDCH-P_2V_2 \quad . \quad . \quad (64)$$

For the engine working in continuity the work developed during a half cycle, or for one stroke of each cylinder, or by each high-pressure cylinder full of steam, will be the sum of (63) and (64), or

$$U=(P_1V_1-GEDK)+(IDCH-P_2V_2)$$
$$=P_1V_1-P_kV_1Q-P_2V_2+P_kV_2S \quad . \quad (65)$$

But in these equations P_k is as yet unknown. Regarding J and J′ as coincident on the adiabatic KG produced, then from the proportionality of horizontal intercepts between adiabatics, we may write

$$\frac{HK}{IJ}=\frac{AC}{AD}=\frac{V_2+V_1+V'}{V_1+V'}=1+\frac{V_2}{V_1+V'}$$
$$=\frac{V_2}{IJ}=\left(\frac{P}{P_k}\right)'=1+\frac{V_2}{V_1+V'}.$$

Also,

$$\frac{P_i}{P_1}=\left(\frac{V_1}{IJ}\right)^n=\left(\frac{V_1}{V_2}\right)^n\left(1+\frac{V_2}{V_1+V'}\right)^n. \quad (66)$$

Hence

$$\frac{P_iP_k}{P_1P_i}=\left(\frac{V_1}{V_2}\right)^n\left(1+\frac{V_2}{V_1+V'}\right)^{n-a}=\frac{P_k}{P_1}=\frac{P_2}{P_1} \quad (67)$$

This introduced in (65) gives in known terms the amount of work per high-pressure cylinder full of steam, viz.:

$$U=P_1V_1\left\{1+\left(\frac{V_2}{V_1}S-Q\right)\left(\frac{V_1}{V_2}\right)^n\left(1+\frac{V_2}{V_1+V'}\right)^{n-a}-\frac{P_2V_2}{P_1V_1}\right\} \quad . \quad . \quad . \quad . \quad (68)$$

If $a=n$, the term $\left(1+\frac{V_2}{V_1+V'}\right)$ drops out. For a and $n=1$,

$$U'=P_1V_1\left\{\begin{array}{l}1-\frac{V_1+V'}{V_2}\text{ hyp.log.}\left(1+\frac{V_1}{V'}\right)\\ -\frac{P_2V_2}{P_1V_1}+\left(1+\frac{V_1+V'}{V_2}\right)\times\\ \qquad\text{hyp. log.}\left(1+\frac{V_2}{V_1+V'}\right)\end{array}\right\} \quad . \quad . \quad . \quad . \quad . \quad (69)$$

If $V'=\infty$, and a and n as in (68), we get

$$U''=P_1V_1\left\{1-\left(\frac{V_1}{V_2}\right)^n+\left(\frac{V_1}{V_2}\right)^{n-1}-\frac{P_2V_2}{P_1V_1}\right\} \quad . \quad . \quad . \quad . \quad (70) \text{ or } (39)$$

the same as (39).

If $V'=\infty$, and a and $n=1$, we get

$$U'''=P_1V_1\left(2-\frac{V_1}{V_2}-\frac{P_2V_2}{P_1V_1}\right) \quad . \quad (71) \text{ or } (40)$$

the same as (40).

One fact to be observed particularly, in comparing these equations with those for the V solution, is the perfect agreement of the expressions for the work U as soon as V′ is made infinite. This is evidently as it should be, since for an infinite volume of receiver it would not matter whether the high pressure exhausted into it immediately on completion of stroke, or whether the exhaust were stayed each time during the half stroke; because the pressure could not vary appreciably in the infinite receiver during this time. For the infinite receiver it is only essential that equal weights be received from the high cylinder, and delivered to the low cylinder per stroke, the strokes being regarded as the same per minute for one as for the other cylinder.

The coincidence of the expressions for work, for the case of an infinite receiver, is therefore expected; and the fact of coincidence corroborates the analysis.

These equations (68) to (71) serve in calculations for duty where the whole work done for a period is compared with the coal consumed. In selecting the equation for use, judgment must be exercised as to the degree of approximation necessary in the case, and as to the proper values of a and n. Wet steam will require different values than dry, the value of a for such case being more properly m, as found in the table following equation (1).

Pressure at Different Points of Steam Action.—To determine the pressure of the steam at different points of action in the engine, we observe first that for $V'=\infty$, the pressures at H, I, J, and K, Fig. 15, become one and the same; that is to say, the pressure in the receiver remains constant, and the indicator diagrams for the two cylinders are simple rectangles.

For the pressure at I or J see Eq. (66).

For the pressure at H or K see Eq. (67), where $P_k=P_2$.

These give the initial and terminal back pressures in the low cylinder, and the initial back pressure in the high cylinder. The terminal back pressure in the high cylinder is $P_g=EG$, for which, by aid of Fig. 15, we may write

$$\frac{P_g}{P_k}=\left(\frac{V_1+V'}{V'}\right)^a=\left(1+\frac{V_1}{V'}\right)^a.$$

Combining with (67),

$$\frac{P_g}{P_k}\frac{P_k}{P_1}=\left(1+\frac{V_1}{V'}\right)^a\left(\frac{V_1}{V_2}\right)^n\left(1+\frac{V_2}{V_1+V'}\right)^{n-a}=\frac{P_g}{P_1} \quad . \quad . \quad . \quad . \quad . \quad (72)$$

If $V'=\infty$, these equations, as well as (66) and (67), reduce to

$$\frac{P_g \text{ or } P_i \text{ or } P_2}{P_1}=\left(\frac{V_1}{V_2}\right)^n \quad . \quad . \quad (73)$$

a common pressure, or a constant pressure of receiver, as above stated, for the case the receiver is infinite in volume. This equation also shows that n is the only exponent upon which the pressure of the infinite receiver depends. It also gives the pressure to which that of the receiver approaches as V′ is made relatively very large.

Equation (67) shows that if $a=n$, as it will nearly for wet steam, the pressure at H or K, $=P_2$, will be entirely independent of V′ whether $V'=\infty$ or not. In this case the larger the receiver the greater will be the proportion of work done by the high cylinder, and the less by the low

cylinder, as indicated by Fig. 15. The pressure P_2 is here the pivotal pressure.

It is a curious fact that for $a=n$, the so-called pivotal pressures, for both valve movements shown in Fig. 13 have one and the same value; as indicated by equations (36) and (67) for $a=n$. That is to say, for given initial pressures and ratio of cylinder volumes the pressures of P_g of Fig. 14, and P_k of Fig. 15, are equal and constant, whatever the value of V'. Again it is immaterial to this pressure whether $a=n$, or $V=\infty$; and it is given by (44) or (73), another evidence that for the infinite receiver the mode of operation of valves is unimportant, whether according to 1st or 2d of Fig. 13.

The ratio of equations thus:

$$\frac{(42)}{(67)} > 1$$

shows that the second valve movement results in a greater ratio of expansion than the first when V' is not infinite.

Relative areas of Indicator Cards.—To find the relation between the amounts of work developed by the high pressure cylinder and the low, we may take their ratio thus:

$$\frac{\text{Wk.H.Cyl.}}{\text{Wk.L.Cyl.}} = \frac{1-Q\left(\frac{V_1}{V_2}\right)^n\left(1+\frac{V_2}{V_1+V'}\right)^{n-a}}{S\frac{V_2}{V_1}\left(\frac{V_1}{V_2}\right)^n\left(1+\frac{V_2}{V_1+V'}\right)^{n-a}-\frac{P_2V_2}{P_1V_1}} \quad . \quad . \quad . \quad . \quad (74)$$

For a and $n=1$;

$$= \frac{1-\frac{V_1+V'}{V_2}\,\text{hyp.log.}\left(1+\frac{V_1}{V'}\right)}{\left(1+\frac{V_1+V'}{V_2}\right)\text{hyp.log.}\left(1+\frac{V_2}{V_1+V'}\right)-\frac{P_2V_2}{P_1V_1}} \quad . \quad . \quad . \quad . \quad (75)$$

If $V'=\infty$, and a and n as in (74),

$$= \frac{1-\left(\frac{V_1}{V_2}\right)^n}{\left(\frac{V_1}{V_2}\right)^{n-1}-\frac{P_2V_2}{P_1V_1}} \quad . \quad . \quad . \quad . \quad (76)$$

If $V'=\infty$, and a and $n=1$,

$$= \frac{1-\frac{V_1}{V_2}}{1-\frac{P_2V_2}{P_1V_1}} \quad . \quad . \quad . \quad . \quad (77)$$

Equations (76) and (77) are seen to be identical with (47) and (48), which is evidently correct for the infinite receiver.

The heat required for making the steam, also the expression for the efficiency is evidently the same here as in the first form of engine.

Maximum Efficiency.—The maximum of (68) or (69) may be found by the same process as indicated for (37) or (38). The maximum of (70) is the same as for (39), because the equations are identical. Hence for U'' the conditions for a maximum are obtained from (50); also (51) follows for $n=1$. Hence the maximum values of U'' and U''' for the present case are found in equations (52) and (53).

But it is a remarkable fact that the maximum efficiency of this engine is exactly equal to that of the Woolf engine, without receiver, shown in Fig. 9 above. That is to say, when $a=n=m$, equation (15) is the maximum of (68). This can be proved by using for the expression of the work, the same as (68) obtained by aid of (57), and the corresponding one for the L-cylinder; also (67); and finally the relations

$$\frac{V_2}{V_1}=\frac{V_1+V'}{V'}=\frac{V_1+V_2+V'}{V_1+V'},$$

obtained from Fig. 15, on the supposition that V' is made so small that the compression line KG is so raised that it extends from K direct to F. This compression line then becomes a cushion line, such that on the return stroke of the H-piston, the remaining steam is compressed and forced into the receiver until at the end of the return stroke the boiler pressure is just restored at F.

The size of the receiver for this special case is $V'=\frac{V_2^2}{V_2-V_1}$; also the isodynamic expansion now vanishes so that this maximum is general.

Conditions for Equal Work of Cylinders.—That the cylinders do equal work, the numerator and denominator of (74) must equal each other which condition gives

$$\frac{P_2V_2}{P_1V_1}=\left(Q+S\frac{V_2}{V_1}\right)\left(\frac{V_1}{V_2}\right)^n\left(1+\frac{V_2}{V_1+V'}\right)^{n-a}-1 \quad . \quad . \quad . \quad . \quad (78)$$

the solution of which may be proceeded with as suggested for (54).

If $V'=\infty$, this expression reduces to the same as (55), as it should; also to (56), for $n=1$. This last is seen to be the same condition as for the maximum efficiency, for $V'=\infty$ and $n=1$, as stated for the first engine, in which respect the engines agree.

The Infinitude of Possible Pump Movements.—In all the preceding cases the piston motion has been regarded as such that when one piston moves for making its complete stroke the other piston stands still at the end of its cylinder, and *vice versa*, as first done in the celebrated Worthington pumping engine, and recently in many others. But compound pumping engines are in use in which we find the three parts V_1, V_2 and V' as above, but with different piston and valve motions, as, for instance, in case of certain Cope & Maxwell pumping engines.

Respecting the possible variety of engines due to unlimited suppositions for piston motion, or valve motion, or both, it appears to be infinite. For almost any one of these the diagrams corresponding with Figs. 14 or 16 become exceedingly difficult to delineate, except for the simple case $V'=\infty$. For instance, there might be the tarrying of the pistons, each for half or other fraction of its time; but with the relative period of strokes indifferent. The steam cylinders might be of equal volume, while one makes twice as many strokes as the other, and thus obtain expansion. This is admissible with or without tarrying of pistons. While the high piston tarries, its valve might open into the receiver at any point of time in the period of tarrying. And the low cylinder might close its valve from the receiver at any point in the tarrying of its piston. A comparatively simple case is that where the pistons do not tarry, and where the valves all work promptly on the termination of the strokes of their respective pistons. But here the periods of strokes of pistons might be in any given relation.

VII.—Strokes Co-initial and Co-terminal; without Tarrying.

For this case a little consideration will show that it matters not at which end of stroke one piston is, while the other starts at a particular end; because, for either one piston, the same changes occur at one end as at the other end of stroke. And let there be no tarrying, but both pistons moving continuously. For this, a little consideration will show that this engine may be rotative, with cranks at 180°, and one cylinder to each, and that it is the same as Case I, and Fig. 4.

VIII.—Strokes Interfluent, without Tarrying.

As an example of a case not quite so simple, and to show the effect of interruption due to the exhaust into the receiver from the high cylinder while the low cylinder is making its stroke, let the reversal of stroke for either piston be at the midstroke of the other. Then Fig. 16 may serve to indicate the relation between piston positions for continuity. The part H refers to the high cylinder, and L to the low. Now suppose H on the point of exhausting into the receiver, and let a represent the beginning and a' the end of this operation. This takes place at the midstroke, a, of the L-piston, as shown in the L part of the diagram. As H exhausts, the volume of receiver and connections will increase in the operation by an amount aa' on a proper scale. Now the H-piston travels from a' to b, while the L-piston travels from a to b. Then the L-cylinder exhausts into the air or condenser, and its volume is cut off from the receiver to begin a new cylinder full. This volume cut off from the receiver is bb', as shown on the L part of the figure. This takes place at the midstroke b of the H-piston; see Fig. 16. And thus these operations continue, as can readily be traced from Fig. 16.

Now when a piston makes a half-stroke, the change of volume of the receiver and connections will not change by that amount alone, because two pistons are in action simultaneously, and the change of volume just referred to will be due to the combined movements of pistons, one of which (the H) is compressing, and the other (the L) is expanding this volume. We observe that the high piston *always* compresses, and the low expands this volume.

The letters a, b, c, d, etc, on Fig. 16, for any one letter denotes a single point of time, so that by referring to any single letter we can at once see the relative po-

sitions of both pistons. The stretches between a and a', c and c', etc., or b and b', d and d', etc., indicate shifting of action from end to end. Thus, when the exhaust is completed from one side of the H-piston, it immediately begins from the other side.

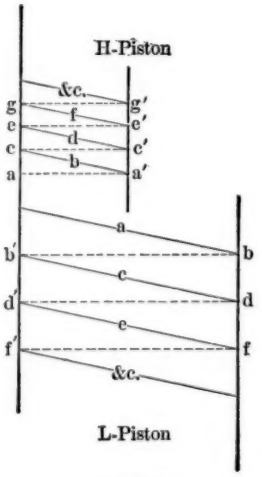


FIG. 16.

For the simultaneous positions, a, we see that the L-piston is at midstroke, while the H-piston is exhausting. Just before beginning the exhaust, a, the total volume in the receiver and connections is $V' + \frac{V_2}{2}$, and just after it is $V' + \frac{V_2}{2} + V_1$, as can easily be traced. For the point b, the H-piston is at midstroke, and the L-cylinder is on the point of exhausting and changing the volume from

$$V' + V_2 + \frac{V_1}{2} \text{ to } V' + \frac{V_1}{2}, \text{ etc., etc.}$$

These changes of volume of receiver and connections are better shown in Fig. 17.

The Complete Diagram.—The shaded areas of Fig. 17 are the indicator cards for the cylinders. The volumes indicated show to which either card belongs. All besides the shaded cards are construction lines used in obtaining the expansion lines and cards.

The lower part of the figure shows the variations in volume. $AB = V'$ is the volume of the receiver itself. At a we have the L-piston at midstroke, while the volume in the receiver and connections is $V' + \frac{V_2}{2}$ as shown. Also the H-cylinder is ready to exhaust, and add the volume $aa' = V_1$. The line at $a'b$ is the variation of volume in the receiver and connections for the half-strokes shown for $a'b$ and ab in Fig. 16. Both pistons move for this, one to reduce, and the other to enlarge the volume considered. The result is an enlargement to the point b, or to the volume $V' + V_2 + \frac{V_1}{2}$. Then the L-cylinder valves are reversed, and the volume $bb' = V_2$ is cut off, leaving only $V' + \frac{V_1}{2}$. The volume $b'c$ is due to combined two half-strokes similarly as in $a'b$. Then cc' is like aa', etc.

Now the expansion line for the change of volume $a'b$, or $c'd$, etc., is $c'd$ above, in the upper part of Fig. 17. This is drawn from A as the zero of volumes. Also the expansion line for $b'c$, or $d'e$, etc., is $d'e$ above. For this the zero is also at A. When the H-cylinder exhausts into the receiver and connections, the volume is raised from

$$V' + \frac{V_2}{2} \text{ to } V' + \frac{V_2}{2} + V_1, \text{ or from C to D;}$$

the steam following from a high-pressure point, C, giving the expansion line Cc', the latter meeting the compression line $cd'c'$ as shown. The resulting pressure is that for the point c'. The expansion from C is for a zero of volumes at D, as will be understood after studying Figs. 14 and 15.

The diagrams are drawn at one side and the other, to avoid confusing the figure.

Now as the H-cylinder exhausts, the pressure becomes that at c', when the H-piston begins its back stroke with a like back pressure. Owing to an increase of volume during this back stroke, the line that would be a compression line for this cylinder alone, becomes a falling or expansion line as shown; first, as far as to d while the L-piston makes a half-stroke; and then as continued to c for the other half, but with a diminishing volume in the receiver and connections. Hence,

the lower line *c'de* of the H-cylinder card is a broken line as shown.

The L-cylinder expansion line is in two parts also, that at *d'e* being due to the fall of pressure for the first half of stroke as traceable by lettering. At the mid-stroke there is a sudden rise of pressure *cc'*, due to the exhaust of the H-cylinder into the receiver. From this point expansion continues on a new line due to a different pressure and volume.

Without entering into analysis, it is probably safe to predict that for an infinite volume the pressure in the receiver will be the same as by (14) and other equations; that is to say, the efficiency is still the same as previously given for an infinite receiver, and nearly so for receivers relatively large. Hence, when the receiver is very large as compared with the cylinders, and when there is no cut-off to either cylinder, the efficiency of engine remains very nearly the same, irrespective of the piston motion or valve motion. Whether there be an advantage in any form of valve or piston motion, for a finite receiver over the infinite, will perhaps be best shown by the numerical results subsequently given.

For the large receiver it is evident that expansion may be obtained equally well, either with equal strokes and unequal cylinders, or unequal strokes with equal cylinders, or both combined.

IX.—The Tandem Duplex Compound Pumping Engine.

This engine differs essentially from the preceding by having four cylinders and no receiver.

Such an engine is shown in Fig. 1, in which there are four steam cylinders, two of one size and two of another size; one large and one small cylinder are seen arranged in line of each one of the two piston-rods. The two on one piston-rod form one complete engine of the Woolf form.

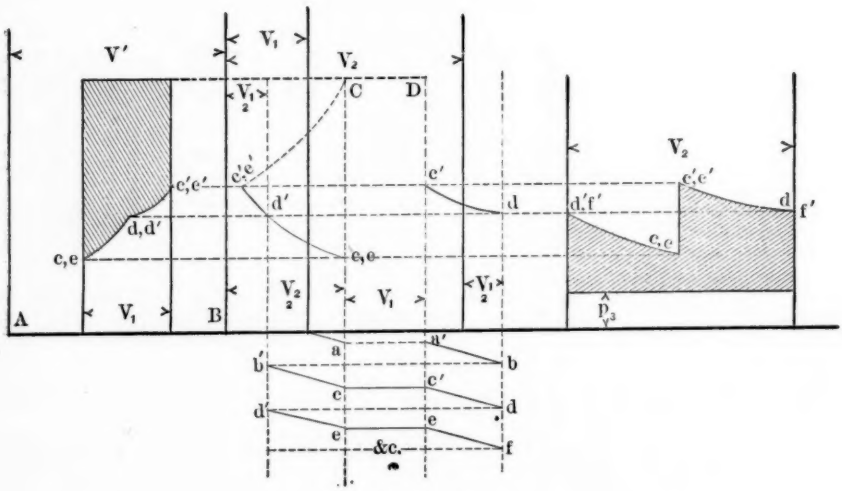


Fig. 17.

Thermodynamically, this engine might be treated without the consideration of duplex, because in reality there are two distinct engines in this form of duplex. We will treat one part as covering the whole in principle.

Here one cylinder may be placed in line with the other, on a common piston-rod, and when so related the arrangement is called "tandem." But the arrangement is immaterial, provided the strokes are co-terminous and without tarrying. The steam is to be delivered directly from the high-pressure cylinder into the low, without the intervention of the receiver. Also, here the steam is

supposed to be admitted to the H-cylinder for the full stroke, and full pressure of boiler; it is then to be exhausted, or transferred to the other cylinder during the whole stroke, which stroke is in common for the two pistons. In this way the volume of steam which occupies the H-cylinder at the end of one stroke, is expanded to the volume of the L-cylinder by the end of the next stroke.

Equation (15) is to be employed for this engine if there be no receiver; or, in the existence of a receiver, even including the intermediate communicating pipe as such, equation (14) will apply.

In these discussions the engine itself is the only part of the machine brought into account, but in the practice of steam pump engineering there are essential considerations relative to the pump as well, some of which have already been referred to.

Numerical Results For Comparison.

A few results have been computed and collected in the following table:

For the first column, (37) was used, and for the second (68); that is, the complete formulas were put to the test.

The feed-water was assumed at the temperature 149° F., and the back pressure 3.62 pounds per square inch, absolute.

The exponent a was taken at $\frac{3}{2} = 1.3333$, n at 1.0456, and for the tandem engine, m was taken at 1.135. The value of a is probably too high for ordinary practice where steam is likely to be supersaturated; probably the best value for practice lies between 1.1 and 1.2.

Table of Results for the V, VI and IX Cases.

P_1	$\frac{P_1}{P_2}$	$\frac{V_2}{V_1}$	*Effy.* V. $V'=2V_2$	*Effy.* VI. $V'=2V_2$	*Effy.* $V'=\infty$, and max. of V.	*Effy.* $V'=\infty$, $n=1$, for VI.	*Effy.* Tandem, and max. of IX.	Work in V_1 / Work in V_2				Press. of admission, P_1 / Press. of exhaust, P_2			
								V.	VI.	$V'=\infty$.	$V'=\infty$ $n=1$	V.	VI.	$V'=\infty$.	Tandem IX.
1	2	3	4	5	6	7	8	9	10	11	12	13.	14	15	16
15.60	4.31	2	.0597	.0790	.0718	.0700	.0842	1.77	.78	1.01	1.	1.96	2.27	2.08	2.17
37.68	10.41	3	.0824	.1055	.0968	.0962	.1238	1.51	.86	1.03	1.	3.03	3.45	3 13	3.45
71.49	19.75	4	.0974	.1230	.1126	.1114	.1547	1.47	.83	1.04	1.	4.17	4.76	4.35	4.76
119.2	32.91	5	.1060	.1326	.1217	.1213	.1755	1.47	.90	1.05	1.	5.26	5.88	5.26	6.25

In looking over the table we at once notice the glaring fact that the tandem engine excels all the other pumping engines in efficiency, and by a considerable percentage. At 23 pounds per square inch apparent pressure, the excess of efficiency of the tandem over the VI is about 17 per cent. of the efficiency of the latter. For 104 pounds per square inch apparent pressure, the same is about 32 per cent.

A second important fact respecting the two valve movements, viz., that of the V and VI is that the latter is a high percentage above the other.

A third important fact appearing in the table, is that in the VI movement, the efficiency is a very considerable percentage greater when the receiver is small than when it is infinite, a fact in support of the conclusions of solutions of VI and VII. Compare columns 5 and 6. For the 5, the receiver is only twice as large as the low-pressure cylinder, and yet the efficiency here is from 8 to 10 per cent. higher than for the engine with an infinite volume.

For V, however, the case is the reverse, but in a greater ratio; that is to say, the efficiency is lowered from 13 to 17 per cent., by changing the receiver from an infinite volume to one only twice as large as the low-pressure cylinder.

As to the value of n, it appears that the efficiency does not change materially when n changes from 1 to 1.0456.

The Cincinnati Telephone Convention, from present indications, promises to be more interesting than any heretofore held.

THE BOWER-BARFF PROCESS.

By A. S. BOWER, C. E., St. Neots, England.

Transactions of the American Institute of Mining Engineers.

ANY process which has for its object the preservation of iron and steel from rust, and which will make these metals more applicable than they now are to the requirements of mankind, will be sure to meet with attention from members of this association, and from all those who are either engaged in the extraction of the ore, its reduction to metal, or the subsequent application of the metal itself.

It is, perhaps, not too much to say that when iron and steel are rendered secure against corrosion and decay, they will be used to an indefinitely greater extent than they now are. The whole realm of science has, therefore, been explored in the attempt to discover some method by which the formed article may be preserved, leaving its strength undiminished by the destructive action of rust. Paints, oils, varnishes, glazes, enamels, galvanizing, electro-depositing and what is called "inoxidizing" are among the many systems now in vogue to effect the preservation of iron and steel from the corrosive action of air and water.

The object of this paper is to show what may be done in protecting iron and steel from rust by forming upon their surfaces a film of magnetic oxide by an inexpensive process. It is no new thing to be told that magnetic oxide of iron is unaffected by exposure to the atmosphere or to salt water for any length of time. The black sand of Taranaki, in New Zealand, is a sufficiently good example of this. Dr. Percy has pointed out that the reason why Russian sheet iron is less affected by exposure than ordinary sheet iron is because of a coating of magnetic oxide; but this was not known until Dr. Percy discovered it. That such a coating is produced is quite certain, but it is only an accident of manufacture. To Professor Barff is due the credit of being the first to deliberately undertake to coat iron and steel with magnetic oxide, produced designedly for the purpose of protecting their surfaces from rust.

Some 16 or 17 years ago my father made a series of experiments in the production of heating gases, one set of them being the decomposition of water by passing superheated steam through masses of red-hot iron. He noticed that the iron became less and less active until it ceased to decompose at all, when, on examining it, he saw that it was coated with a kind of enamel. It at once occurred to him, on seeing this, that the process in question might be used to obtain such a coating, but he found after a few days' exposure of the iron to the atmosphere, that the coating shelled off, and he pursued the matter no further. The iron employed in this case was rusty, but if it had been new my father would in all human probability have been the accidental author of the process which Professor Barff discovered ten years afterward. I only mention this to show how advisable it is to investigate the causes of unexpected effects. Professor Barff's process consists in subjecting iron or steel articles to the action of superheated steam, and when they are at a temperature sufficiently high, three equivalents of iron combine with four of oxygen, forming one equivalent of magnetic oxide, and setting eight of hydrogen free, or symbolically (1) $Fe_3 + 4H_2O = Fe_3O_4 + 8H$.

Upon reading a description of the Barff process in the London *Times*, it occurred to my father that what the Professor could effect with steam he might also effect with air, and several experiments were made to this end, which were very varied in character, as were also the results obtained. The first was made with cast iron, by placing the articles to be treated in a cast-iron retort, heated externally, and then passing superheated air over them; and it was successful, while nearly all the others afterwards were quite the reverse, as sesquioxide was copiously produced as well as the magnetic. Another experiment was made by placing a bar of polished cast iron in the main duct of superheated air to a blast furnace, and this, though covered with a red sesquioxide powder easily brushed off, had a thin, but very firm and

tenacious coating of magnetic oxide in contact with the iron. This bar has been exposed to the weather ever since, or over four years, without the slightest appearance of rust. Ultimately, when thinking over the fact that air is oxygen and nitrogen in mechanical combination only, I came to the conclusion that, to form the lower or magnetic oxide, the quantity of free oxygen, and so of the air employed, must bear some proportion to the surface of the articles exposed to its action, more especially when a comparatively low heat is employed. This is so, and it has been proved that the quantity of air passed through the retort during most of the unsuccessful experiments was 300 or 400 times more than was actually necessary. The reasons also why the first experiment was successful were that a great number of articles were in the muffle, that a very high heat was employed, and the retort had been previously used for coal-gas making, and had a deposit of carbon in it, which to a great extent neutralized the effect of the large excess of air.

All the unsuccessfully treated articles were red with sesquioxide outside; but there was, nevertheless, a coating of magnetic oxide in close proximity with the iron, due to the reducing influence of the metal in contact with the sesquioxide at an elevated temperature. The general appearance however, of iron so treated was disagreeable, to say the least of it. The mode of action I then adopted was to admit a few cubic feet of air into the retort at the commencement of every half-hour, and then to leave the iron and air to their own devices, the retort, of course, being tightly closed. During each half-hour a coating of magnetic oxide was formed, and the operation was repeated as often as was considered necessary. Effective as this was for cast iron, the cost of producing the coating was as great as by the Barff process, for both of them required that the chamber should be heated externally, and this with large furnaces is very expensive. Another plan that I adopted was to first find out approximately the extent of the surface of the goods to be treated, by first dipping them all into a tank of water of known area, lifting them out, and noticing the amount of water taken out of the tank by the wetted surface, and regulating accordingly a slow, continuous air supply by meter, of course keeping the temperature of the muffle as nearly constant as possible. This, too, was successful; but the same objections applied to that mode of procedure as to the other.

There was commenced a series of experiments with carbonic acid chemically produced by the decomposition of chalk, the idea being that three equivalents of iron would unite with four of carbonic acid, forming one equivalent of magnetic oxide, and four of carbonic oxide, if the heat were sufficiently high. This reaction is expressed symbolically thus: (2) $3Fe + 4CO_2 = Fe_3O_4 + 4CO$. This is the simplest action that could take place, but it was evident from the results that something quite different was obtained, inasmuch as the coating was very light in color, pleasing to the eye, but easily removed, and in that sense entirely differing from the articles you see before you. This coating, from effects exactly similar and designedly produced by a studied manipulation in the furnaces in successful operation in England, France and here, proves pretty conclusively that carbonic acid, practically pure, produces upon iron, at an elevated temperature, a film which is, in composition, a mixture of FeO and Fe_2O_3, or, at all events, it is nearer the metallic state than is magnetic oxide. But even supposing that the results obtained by the carbonic acid had been successful as then carried out, the objections referred to concerning the air process would still exist, as external heat and a closed iron muffle would always be necessary. I therefore proposed to use a fuel-gas producer, similar in principle to the Siemens generator, but altered practically to suit other requirements, to burn the combustible gases thus produced with a slight excess of air over and above that actually required for perfect combustion, and to heat and oxidize the iron articles, placed in a suitable brick chamber, by these products of combustion. I also arranged a continuous regenerator of fire-clay tubes underneath the furnace, so that the products of combustion leaving the oxidizing chamber passed outside the tube, imparting a portion of the waste heat to them, which was taken up by the ingoing cold air passing through their interior on its way to the

combustion chamber. I had hoped in this way to be able to so regulate the excess of air over that required for complete combustion as to be able to produce magnetic oxide directly, instead of the lower and useless oxide, or combination of oxides, produced by carbonic acid alone. I obtained some beautiful results, and some again were unaccountably bad, and I soon found that it was as difficult to regulate the precise amount of oxidation as it first was in the Bessemer process, and I was fortunate enough to hit upon an almost parallel remedy—that is to say, I increased the quantity of free oxygen mixed with the products of combustion, and oxidized the iron articles to excess during a fixed period of generally 40 minutes, when magnetic oxide was formed close to the iron and sesquioxide over all. Then for twenty minutes I closed the air inlet entirely, leaving the gas-valve open, and so reduced the outside coating of sesquioxide to magnetic oxide by the reducing action of the combustible gases alone.

The excess of oxygen in the first instance produces Fe_2O_3, or sesquioxide of iron, and the under surface of this being in contact with metallic iron, undergoes reduction to magnetic oxide in the following manner: Four equivalents of sesquioxide unite with one of metallic iron, forming three equivalents of magnetic oxide, or symbolically (3) $4Fe_2O_3+Fe=3Fe_3O_4$.

When deoxidizing by combustible gases, consisting mainly of carbonic oxide, three equivalents of sesquioxide unite with one of carbonic oxide and form two equivalents of magnetic oxide and one of carbonic acid, or symbolically, (4) $3Fe_2O_3+CO=2Fe_3O_4+CO_2$. Another method of reduction is by carbon itself, when the formula stands thus: (5) $3Fe_2O_3+C=2Fe_3O_4+CO$.

Formula (4) is also the reaction when rusty iron is reduced by producer gases which consist largely of carbonic oxide; and by the specimens exhibited it will be seen that articles completely pitted with rust may have their surfaces rendered rustless. In this case of oxidizing and deoxidizing are reversed—that is to say, the latter occupies 40 and the former 20 minutes. No oxidizing is theoretically necessary, but practically a certain amount is requisite to keep up the heat in the chamber, which, of course, could not be done unless combustion took place some time or other. I only mention the reduction by carbon as exemplified by formula (5) because, while experimenting with a furnace, I was asked by the proprietors of a valuable red-oxide deposit, which was found in so finely divided a state as to be capable of being used at once as a paint, whether I could reduce it to a magnetic oxide. I tried to do so by carbonic oxide, but I found that only the surface of it was affected, and that even this, when taken out of the furnace, speedily returned to its original red color, by the combined actions of the hot unconverted material underneath and the air above. It will be found from formula (5) that $2\frac{1}{2}$ pounds of carbon are required to reduce 100 pounds of red oxide. This I mixed intimately, in the shape of powder, with the red oxide, brought the mixture to a red heat and the result was black magnetic oxide. Not only this, but by adding more carbon I could make the color lighter and lighter until it was almost identical with the coating produced in my previous experiments with carbonic acid, and by reducing the quantity of carbon below $2\frac{1}{2}$ per cent. various shades of purple were obtained, the red appearing more and more prominent as the quantity of carbon was diminished.

It will be as well, before I make any comparison between Professor Barff's process and the processes patented by my father and myself, to state that the whole of the Professor's patents, wherever existing, have been purchased by my father, so that in this case, at least, I hope you will not say that "comparisons are odious." Professor Barff's process is better than ours for wrought iron, and perhaps for polished work of all kinds, as iron commences to decompose steam at a very low temperature; in fact, much below visible redness. Only the other day at the annual meeting of the Association of American Stove Manufacturers, held in New York, I was asked whether stove patterns might not be made of cast iron, polished and then oxidized? Here is one among many instances where the steam process is almost invaluable. For ordinary cast iron, and especially that quality which contains much carbon, the Barff process is much too slow in its

action, and some specimens that I have treated in England have taken as much as 36 hours to coat effectually, which could readily have been finished off in five hours by the Bower process.

The main distinction between the two is that the Bower is much more energetic in its action than the Barff process. The carbon in cast iron impedes oxidation, and so, while cast iron is far more readily treated in the Bower furnace, wrought iron is apt to scale unless it is rusted beforehand. The rust then eats into the metallic surface under the influence of heat, and forms a tenacious combination with it. The objection to the use of a closed muffle externally heated, as in the Barff process, has been almost entirely overcome by simply putting wrought iron into a Bower furnace, previously well heated, then shutting off both the gas and air supplies, and admitting steam into the regenerator tubes. The steam thus passes through the red-hot tubes, then through the combination chamber and its contingent passages already highly heated, over the articles in the oxidizing chamber, heating and oxidizing them, and thence over the outside of the regenerator tubes, depositing a great portion of its heat there before passing to the chimney, and which is again picked up by the ingoing fresh, cooler stream. In this way the heat in the chamber is highest shortly after the commencement of the operation, and gets gradually lower during the time of exposure, which varies according to the class of goods, from five to ten hours. At the close of the operation, just before the articles are taken out, everything is moderately cool, and this for steam is the perfection of action, as stated by Professor Barff himself. Steel, I consider, can be equally well treated by both processes, and, indeed, it is natural to expect this, steel being, so far as the quantity of carbon it contains is concerned, between cast and wrought iron. Polished steel, however, is better treated in a low-temperature Barff furnace.

With regard to the quality of fuel burned in the gas producers, a non-coking gas coal is the best, and Virginia splint has suited very well in this country, and of this about 1 ton every three days is required for a furnace with an oxidizing chamber 13 feet long, 4 feet 3 inches wide and 4 feet 3 inches high. When a gas coal is employed, it should be fed through the charging hoppers just before each deoxidizing operation, when a smoky flame is of great advantage. I have, however, discovered that anthracite can be used as well as a gas coal, by simply allowing petroleum to drop at the rate of 1 gallon per hour upon the red-hot surface of the coal in one of the gas producers. This method has been exclusively used in the coating of the articles exhibited in this room, at the works of Messrs. Poulson & Eger, architectural engineers, at North Eleventh and Third Streets, Brooklyn, E. D., N. Y., to whom I am much indebted, not only for these beautiful castings, but for the constant courtesy and energy they have always exhibited during the erection of their furnaces. At present they have two erected, one a Bower furnace of the size before mentioned, and the other a small Barff furnace for the treatment of very delicate or polished articles.

These magnetic-oxide processes not only protect from rust, but the coating is of such a beautiful color as to render articles ready for the market as soon as they are out of the furnace and cooled. One remarkable feature of them is that there is no more cost (except in the labor of handling them) in treating 2240 articles, each weighing a pound, than there is in coating a cube of metal weighing a ton; and so penetrating is the process that no matter how intricate the pattern may be, every crevice—which it would be almost impossible to get at with a paint-brush—is as effectively coated as the plainest surfaces as will be observed by examining the specimens exhibited. For art purposes the French gray color, with shades approaching to black, might not always be suitable; but if it should be necessary to use paint on the iron so coated, there is an absolute certainty that it will remain on in the same way as it does on wood or stone, and thus iron may be used for constructive work in a thousand directions in which it has not up to the present time been possible on account of its liability to rust, no matter what the coating used to protect it has been.

I can give an instructive instance of this. A company in Paris had expended a very large sum over Dode's inoxidizing process, which process consists in the

depositing of a layer of borate of lead on iron or steel and then gilding, platenizing or bronzing them; and certainly the articles so treated were exceedingly beautiful to look at. But the iron ultimately rebelled and threw off the coating, so that the shareholders were in a fair way of losing all their capital, when it was suggested to the directors that if their compositions could be deposited direct upon magnetic oxide they would conquer the difficulty. They then applied to my father for specimens of coated iron to experiment upon, and they were so well satisfied with the result that the company purchased all our European patents except those for England, and are carrying on the combined processes on a large scale. They have, besides their furnaces for the Dode process, four large Bower furnaces, two being 36 feet long by about 6 feet 6 inches wide and 6 feet high, and a Bower-Barff furnace, also of large size. Others, moreover, are in course of erection.

Engineers and manufacturers appear far more ready to apply the processes here and on the Continent of Europe than up to the present time they have been in England. Perhaps the reason has been that, so far as Professor Barff's process is concerned, it has only just been shown how large masses can be dealt with—namely, by the use of the Bower furnace. I can show that, for the treatment of underground pipes, wrought-iron sleepers, roofing, and the like, the process can be readily applied, and at a cost much less than that of galvanizing, and they will at the same be infinitely more durable; while for ornamental cast and wrought iron it is scarcely possible to imagine anything more artistic in color than some of the articles after they have been treated. For ordinary hollow-ware for kitchen use, whether of cast or wrought iron, this process is admirably adapted, and though I have been told that the gray or black color will probably be objectionable, yet I imagine, if it can be shown, as can be done, that the magnetic oxide is more durable, more easily cleaned and much cheaper than even the common tinted article, a market will soon be created. Anyhow, the new combined processes are so far developed, and they have been so thoroughly examined by scientific and practical men both here and in Europe (whose testimony to the value and efficacy of them is voluminous), that they have passed from the region of theoretical investigation into that of practical application, and means have been taken for establishing works at different centers in Europe, as will also be done here, for the purpose of coating iron and steel as a trade operation. One firm alone in Scotland, Messrs. Walter Macfarlane & Co., have adopted the process, and their output of ornamental castings per day exceeds 100 tons. It is intended to apply the process to cast-iron gas and water pipes, and as the former have comparatively no pressure to bear, they may be made much lighter than they now are, if rendered incorrodible; while for water, it will be a great advantage to have both the main and service pipes rendered safe from rust, which not only discolors the water, but forms the nucleus of very troublesome deposits. There is no reason now why wrought-iron or mild-steel pipes should not be used for the same purposes, especially for the interior towns of distant countries, where the first cost of the pipes is but small as compared with the cost of carriage.

My father has himself used gas and water pipes where the cost on arrival at their destination has been five times greater than their first cost in England. If, then, light wrought-iron, or steel pipes could be used, not weighing one-third of those made of cast-iron, and rendered practically indestructible, what an enormous saving will be effected! Again, in the case of railway sleepers in iron and steel, which are now almost wholly used in Germany, the process is likely to prove of much advantage, so at least I am told by engineers, both in Belgium and in Germany; and if there, why not here? For fountains, railings and all architectural work the process is invaluable, and iron may now be used in many instances instead of bronze.

It will naturally be asked, what is the cost of the process? I cannot do better than answer the question by quoting from the report of Professor Flamache, the engineer-in-chief of the State railways in Belgium, who was sent over specially to England to report on the process by the Public Works Department of that country. His estimate of cost,

after a very careful examination and testing of the process, was 7½ francs per 1000 kg., or nearly $2 per ton, at, of course, the Belgian rate of expenses. He also gives the cost of coating a certain extent of surface, but this I consider to be completely valueless, as, for example, I have had a furnace full of 56-pound weights. and another time I have had it full of gas-governor tops, the surface in the latter case being perhaps one hundred times more in extent than in the former, while the actual cost of oxidizing would be the same in both cases. He also says that this cost may be reduced, as instead of one workman attending to one furnace he can attend to three or four; also by a better system of taking the articles out than existed in the experimental furnace that he saw.

Sir Joseph Whitworth, feeling much interest in Professor Barff's process, sent to him some steel to be oxidized, so that he might ascertain whether it did or did not lose in strength by the operation, and the result of Sir Joseph's testing was that there had been no alteration whatever. Theoretically, one would rather expect that iron and steel would be somewhat toughened, as the tendency of the process is to anneal, and would, no doubt, if continued long enough, render some classes of cast iron malleable. A very thin article, if excessively coated, might probably be weakened, due to the fact that the coat of magnetic oxide would form an appreciable percentage of the bulk of the article; but this, of course, is a very extreme case, and one which is not likely ever to occur in practice.

The development of these processes has been a long and tedious business, and one requiring much faith and patience in the midst of most disheartening failures for months together; but to gentlemen connected with the iron and steel industries, and who know well that results are only obtained by patient and well-directed toil, I need not dwell on this, as almost every man who has had to reduce theory to practice has had abundant experience of the same kind.

A REVIEW OF PROF. S. W. ROBINSON'S LONG COLUMN FORMULA.

By WILLIAM H. BURR.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

HAVING lately had occasion to examine the column formula given by Prof. S. W. Robinson in this Magazine for June, 1882, I find myself compelled to take exception to them, both in regard to the analysis on which they are based and on the ground of their disagreement with actual tests.

In the first place, he employs the "common theory of flexure" as the instrument to establish his formula, recognizing, as is usual, the fact that the condition of stress at any section of the column is a resultant of pure compression combined with pure bending. At just what point the common theory of flexure becomes approximately applicable to pieces under combined compression and flexure is not yet precisely established by experiment; but a sufficient number of experiments exist to show that it is not below a length equal to two hundred radii of gyration of section. To demonstrate that a formula based simply upon the common theory of flexure (as this is) gives results agreeing closely with actual tests is proving altogether too much, unless the columns are excessively long. From the very nature of the case it is not possible to produce a formula so based which shall represent with tolerably close approximation the ultimate compressive resistance of such columns as are ordinarily used in bridge construction. All that ever has been done of a reliable character, is to produce a *form* of formula in which empirical coefficients may be introduced. Even such formulas are applicable only within restricted limits; yet they have had great practical value.

Again, any formula for rupture deduced by the aid of the common theory of flexure, carries a supposition of a perfectly

elastic condition, even to the point of failure. No such condition exists in ordinary long columns, including those by which Prof. Robinson tests his formulas. It may be urged, however, that his formulas *do* give tolerably close agreement with the experiments cited by him. But in reality those results are neither sufficiently continuous nor extended in range of length over radius of gyration to furnish anything approaching a critical test of his formula. And again, a close consideration of Prof. Robinson's analysis reveals some singular characteristics, that in one or two instances, at least, take the shape of positive error, and which lead to an explanation of discrepancies which will subsequently be shown to exist.

On pages 490 and 491 in the June, 1882, No. of this Magazine, he takes moments first about the center of gravity of the column section and then about some line parallel to the first axis and without the column, while he proceeds to combine them or treat them separately as if they involved independent conditions and as if one would give some result which the other would not. In reality either of the equations so formed is simply an equality between the bending moments of external forces and internal stresses, and either one can be derived from the other by adding or subtracting the same thing to or from each member of the latter. Such equations involve precisely the same general conditions, and give nothing except two forms of the common difference between the members, and in this case that is not needed.

At the top of the second column on page 491, Prof. Robinson shows by taking moments about an axis passing through the center of gravity of the column section, that "when a compressive force, T, is applied at the distance, k, (radius of gyration) from the center of the cross section of a prism, the displacement, EF, due to bending, is exactly equal to the displacement, FG, or BC, due to direct compression"; references belong to his Fig. 22. But his Fig. 22 shows that if FG=EF=BC, the distance BD of the neutral axis from the center of gravity of the section must be equal to BE, the distance of the line of action of the compressing force T from B, the center of gravity; *i.e.*, when $y_1=k$, BD $=y_1$. It is important to observe that BD is proved equal to y_1 *only when* T *is applied at* E.

After showing these results, Prof. Robinson then takes moments about a neutral axis which he supposes at a distance qk from B "while T is applied at E." But it has just been seen that his first moment equation proves that "while T is applied at E," qk must equal k, or $q=1$. However, let us follow his analysis.

The moment equation preceding his Eq. (92a) gives:

$$\mathrm{T}qk=\frac{\varepsilon \mathrm{K}}{\rho}q^2k^2.$$

Or, since $\mathrm{T}=\varepsilon \mathrm{K}\lambda$, and since he has just proved that when T is applied at E, $k=\rho\lambda$, the above equation gives $q=1$, just what his first moment equation proves. The two moment equations, therefore, give the same result, as was to be expected. But immediately under the above equation, or value of Tqk, Prof. Robinson writes:

$$\mathrm{T}k=\frac{\varepsilon \mathrm{K}}{\rho}qk^2 <= \text{ or } > \frac{\mathrm{T}}{\rho\lambda}k.qk.$$

He gives no warrant for these inequality signs. The equation, mathematically exact, stands:

$$\mathrm{T}k=\frac{\varepsilon \mathrm{K}}{\rho}qk^2;$$

there is no possible variation in the value of the second member. None of the conditions of the problem permit such latitude; the equation is simply one between the external bending moment and that of the internal stresses. After introducing these inequality signs, without warrant or right, as has just been seen, Prof. Robinson proceeds to show that although he assumes q may vary, yet it cannot be greater or less than unity, and hence, must equal that quantity.

When he has thus shown for Fig. 22, that under the condition of T being applied at E, BD=BE=$k=y_1$, he at once leaps to the astonishing conclusion "we therefore follow the conditions that in Eqs. (90) to (92), BD$=y_1$." Having shown that for one special point of application of T, that BD$=y_1=k$, he generalizes to the effect that in a bent column the normal distance from the line o action of the applied force to the center

of gravity of the column section, at its point of greatest deflection, is equal to the normal distance from the latter point to the neutral axis. Nothing could be more erroneous; at least, he should prove it and not assume it. The logical process would require a *general* result to be established from which, by the introduction of particular given conditions, a special one would proceed.

By means of this erroneous operation Prof. Robinson finds a value of the greatest intensity of compression (t) which involves the radius of curvature of the column at the place of greatest bending; the same value also involves the greatest deflection y_1. He then writes the greatest bending moment in terms of the total compressive resistance (T) of the column.

At this point of his analysis we are surprised to observe that he is obliged to use the value of the compressive resistance of the column as given by Euler's formula in order to eliminate that force (T) from one of the equations just mentioned. He states half a page further on that he does not use Euler's formula as a "foundation" of his own. Whatever may be his intention, however, as a matter of fact he takes the compressive resistance of a long column as given by the oldest column formula and introduces it into his own equations. Now if T is given by Euler's formula, what is needed of his Eqs. (97), (98), (99) and (100)?

The signification of these operations will be noticed further on.

His long column formula as actually given are his Eqs. (97), (98), (99) and (100). As good a series of experiments as can be chosen, probably, for the purpose of testing the accuracy of a formula is that made on Phœnix columns in Nov. 1879, and given in *Trans. Am. Soc. Civil Engineers*, January, 1882. The range of this series even, is too limited for the purpose, but its continuity is eminently satisfactory. These columns had flat ends, hence:

$$T=\frac{tK}{1+\frac{d_1^2}{2k^2}\left(\sqrt{1+\frac{tl^2}{\pi^2\epsilon d_1^2}}-1\right)} \quad . \quad (1)$$

But a difficulty at once confronts us in applying this formula, which indicates an error of some sort in its very form. A Phœnix column is equally liable to fail in any direction, if its ends are simply "flat," while d_1 (distance of most remote fibre from neutral axis) has different values in different directions. Eq. (1) indicates that T may vary with d_1. Now which value shall be taken in the present case, in which d_1 may vary from about 4.1 to 5.8 inches? For these columns $k^2=8.94$, and in consequence of the indetermination regarding d_1, there was taken about a mean value of $\frac{d_1^2}{2k^2}$, *i.e.*, that value was taken at 1.5. Taking $t=40000$ and $\epsilon=27{,}000{,}000$, Eq. (1) may be put in the form:

$$\frac{T}{K}=p=\frac{40000}{\sqrt[3]{2}\sqrt{1+0.00005\frac{l^2}{k^2}}-0.5} \quad . \quad (2)$$

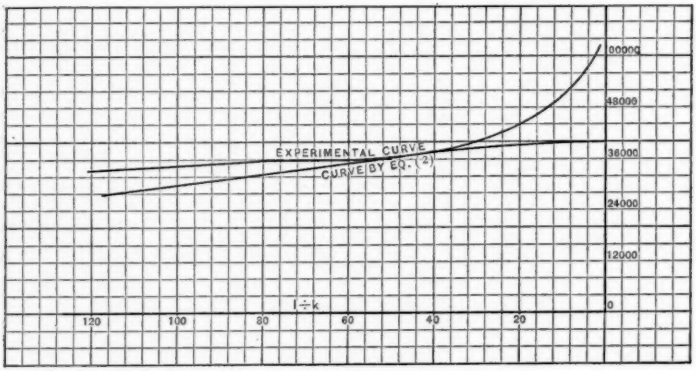
The accompanying table gives some of the data of the columns together with the results of the tests; also the values in the column "p" found by the application of Prof. Robinson's formula, *i.e.*, Eq. (2).

PHŒNIX COLUMNS.

No.	Length.	$l \div k$	Exp.	p.
	Feet.		Pounds.	Pounds.
1	28	112	34650	28300
2	25	100	35150	30000
3	22	88	35000	31570
4	19	76	36130	33250
5	16	64	36580	34780
6	13	52	37000	36430
7	10	40	36440	37770
8	7	28	40700	38830
9	4	16	50400	39640
	Inches.			
10	8	2.7	57200	40000

The column "Exp." contains the means of two experiments on each length of post. Each way from Nos. 5, 6 and 7, there is a constant and rapid divergence of the formula from actual results of tests. In view of the fact that there are a number of formulas of both Euler's and Tredgold's forms which, with empirical coefficients, give far better results and through a wider range than Eq. (2), the above table shows Prof. Robinson's formula to be of little or no practical value even if its analytical basis were correct.

The adjacent figure gives a graphical representation of the results in the table and shows the formula to be yet more unsatisfactory, because its curve is convex, or concave, in the wrong direction. Again, the Eq. (2) and its curve show the greatest possible unit resistance of wrought iron in blocks to be 40,000 pounds per square inch, whereas that material has an ultimate resistance to compression of 55,000 to 60,000 pounds.



But why, it may be plausibly urged, if the formula is so erroneous in its nature, are not the variations from actual test still greater?

With a little consideration the reason is obvious. Prof. Robinson's analysis really belongs to a block, or column, of material in which the resultant stress in the middle section, at least, is *explicitly* assumed to act at the distance k from the center of gravity, while he *implicitly* assumes the resistance of the same piece of material to be given by Euler's formula, after which he proceeds to establish his result in the ordinary manner when treating of combined compression and flexure.

Now such a *mêlange* involves just enough of truth, and approximation thereto, not to give results at random, but which are far enough from expressions of a true law.

Besides the fact indicative of error that the formula involves d_1, as has already been noticed, if it were not incorrect its results ought to agree with those of Euler's for very large values of $l \div k$. But Prof. Robinson does not show that there is more than one point of agreement, whereas there should be coincidence for all very large values.

Although not relevant to the matter under discussion, it is proper to observe in this place that Prof. Robinson seems to hold, as some others do, that Euler's form of formula contemplates only pure bending, and not combined bending and compression. As a matter of fact it belongs to a piece under combined compression and bending just as completely as Tredgold's form, *i.e.*, the many varities of Gordon's or Rankine's formula. Both forms involve the same conditions precisely, and are subject to the same limitations in respect to the common theory of flexure and elastic conditions of the material, and to no other.

M. DE MOLINARI calculates that the municipal expenditure of Paris equals that of London, although it has not two-thirds of the population. The most expensive capital on the Continent from a ratepayer's point of view is Munich. But after Munich comes Paris, with an annual expenditure of £4 per head of its population. The expenditure of London, including loans, is about £2 16s. per head. Both London and Paris spend £10,000,000 on their local government. Berlin is much more economical, the rate per head in the Prussian capital being only £1 17s. 6d. per annum.

EXPERIMENTS ON IRON AND MILD STEEL.

From "Iron."

THE Aix-la-Chapelle branch of the German Engineers' Union have lately had before them some valuable experiments on the use, as a material of construction, of what they now call Flusseisen, and we call either ingot iron or mild steel. The question was raised by a paper by Prof. Intze, who strongly recommended the material on the ground of a series of tensile tests. At a subsequent meeting a letter was read by Herr Offergeld, of the Duisburg Bridge Works, describing comparative experiments made at those works on riveted girders of mild steel and wrought iron. The steel was made specially for the experiments by Krupp, it being found that the steel bought in market was not sufficiently uniform for such tests; in fact, this want of uniformity, together with numerous failures in the works, had compelled that company to abandon the use of steel for bridge work altogether.

The girders, whether of wrought iron or mild steel, were about 6 meters in length (19.7 feet), 700 mm. in depth (2.3 feet), and of the same strength as those employed for railway bridge making. As is usual with such work, when riveted girders are erected, the plates were completely put together, and the holes made in that position, so that it was not necessary to rimer or drift the holes—a practice which was in this case indeed, very carefully avoided. In the tests the girders were secured against bending to a greater extent than is usual in practice. The web plates were strengthened with angle-iron stiffeners, placed 800 mm. apart (2.62 feet); towards the center they were as near as 400 mm. (1.31 foot). Various experiments in mild steel had given the following results:

Breaking strength (F). Kg. per sq. mm.	Tons per sq. in.	Elongation (D). Per cent.	Contraction of area (C). Per cent.
42	26.5	24	49
42	26.5	15	43
48	30.2	24	49

A load of F=28 kg. per square mm. (17.6 tons per square inch) produced in the girder a deformation of 2 mm., which, on removal of the load, proved to be permanent, and which subsequently increased; and here it may be observed, once for all, that all deformations of a local nature occurred in the compressed flange only. Increased pressure next produced a swelling in the web plate close to the stiffener, which continued to increase. The flange yielded correspondingly, and the horizontal angle-irons connected with it crumpled till at F=35 kg. per square mm. (22 tons per square inch) the resistance of the girder was so greatly diminished that a load of F=36 kg. per sq. mm. could not be attained.

A second set of mild steel girders gave the following tests:

Breaking strength. Kg. per sq. mm.	Tons per sq. in.	Elongation Per cent.	Contraction of area. Per cent.
46	29.0	24.0	47
43	26.1	24.5	46
48	30.2	24.5	50

At F=31 kg. per square mm. (19.5 tons per square inch) the lower flange began to bend out sideways. At F=35 kg. the swellings right and left of the center near the stiffeners began, one appearing in front, and the other on the opposite side; the compression flange became S-shaped in plan. The deflection was continued without difficulty from 30 to 94 mm., after which it became so rapid that the pressure could not be increased. The tension flange was bent by 2 mm. (0.08 inch).

A third set of mild steel girders gave the following tests:

Breaking strength (F). Kg. per sq. mm.	Tons per sq. in.	Elongation Per cent.	Contraction of area. Per cent.
49	39.9	23	42
48	30.2	22	45
48	30.2	21	47

The series of effects were exactly the same as before—F=25 kg. per square mm. proved the limit of elasticity, and beyond that the same deformations took place.

The behavior of three wrought iron girders was as follows:

Breaking strength. Kg. per sq. mm.	Tons per sq. in.	Elongation Per cent.	Contraction of area. Per cent.
39	24.6	24	35
40	25.2	21	28
10	6.3	14	24

The girder tests gave at F=35 kg. per sq. mm. (22 tons per square inch) the first signs of yielding in the compression flange. At F=37 kg. the central part of the compression flange was reduced from its original length of 800 mm. to 795 mm., and the tension flange increased to 809 mm., though no alteration in shape was perceptible. It was only under a pressure of F=38 kg. that the double swellings occurred in the web plates, but instead of attaining a depth of 25 mm. (1 inch), they amounted at the most to 10 mm. (0.4 inch). At F=39 there appeared at a row of rivets signs of crumpling in the compression flange. In the tension flange the rivet-heads at the center of the girder, both in the flanges and angle irons, were displaced, and showed small cracks in places.

A second set of wrought iron girders gave the following tests:

Breaking strength. Kg. per sq. mm.	Tons per sq. in.	Elongation Per cent.	Contraction of area. Per cent.
39	24.6	22.5	26
40	25.2	21.0	29
38	24.0	15.0	23

The girder was loaded to F=38 kg. per square mm. without any break becoming apparent; the amount of deformation was immaterial, and as looked at from above, equal, both upper and lower flange being bent out to 15 mm. No swellings appeared. The compression flange, however, both plates and angle irons, was buckled for 1 mm. in length and 3 mm. in depth. The rivet-heads of the tension flange were displaced by 1 mm.

Another set of wrought iron girders gave the following tests:

Breaking strength. Kg. per sq. mm.	Tons per sq. in.	Elongation Per cent.	Contraction of area. Per cent.
40	25.2	23	30
40	25.2	25	31
19	24.6	12	11

These experiments showed at F=35 kg., in the tension flange a small tear of 1 mm., starting from a rivet. At F=38 kg. this tear widened, and a slight yielding in the compression flange became apparent. At F=39 kg. indications of swellings in the web plates showed themselves. A length of 320 mm. diminished in the compression flange to 317 mm., and increased in the tension flange to 331 mm. At F=40 kg. the tear increased. At a deflection of 84 mm. the tear increased so that the horizontal plates appeared to be torn right over both riveting holes; this took place without any noise.

Increased load produced a frequent low cracking, arising, doubtless from the rivets, which were displaced to the amount of 1 mm. The compression flange became severely buckled at a deflection of the girder amounting to 88 mm. (3.5 inches). One of the angles of the compression flange split through. At 90 mm. the tension flange broke through entirely with a dull sound. The breakage of each bar showed both extension and contraction. The two center vertical strips, originally parallel at a distance of 840 mm., showed just below the compression girder a distance of only 822 mm., and just above the tension girder of 858 mm. These experiments show that mild steel is less effective for girders than wrought iron.

The greater tensile strength by 20 per cent. in mild steel is unavailable, because, long before such a tension is reached, the material developes wrinkles in the compressed portions, and this deformation destroys the resisting power of the girder. The resisting power of the wrought iron girder is efficient against even a greater load, and both the tension and compression flange begin to yield at about the same time to the pressure put upon them.

In mild steel also allowance must be made as yet, at least, for the inequalities existing in the material itself, which necessitate the most careful treatment in the working up, as the smallest tear or scratch sometimes causes the whole to go to pieces. The bad results obtained from steel bridge girders must not, however, be ascribed to the fact that 55 kg. per square mm. (41 tons per square inch) is too hard a steel, as in America good results have been obtained with steel of 80 kg. (50 tons per square inch), with an extension of 10 per cent., in bridge work. Steel or this quality was therefore obtained and experimented on. The girders behaved comparatively well. The first

showed a crack at 55 kg. (34.6 tons per square inch), but without losing its strength, which continued till a second crack took place at 68 kg. (42.8 tons per square inch). The second girder cracked first at 59 kg., and lost its resisting power at the same time. The third was not to be broken, but at 69 kg. showed such serious local deformation (of exactly the same quality and degree as in mild steel) that the resisting power was thereby destroyed. That such exceptionally hard steel can be so deflected shows that previous bad results must not be laid down to the score of hardness. The fault lies principally in the inequalities, which cannot possibly be avoided in the making, and which only become the more marked when the material is made in large quantities. Both tho hard and mild steel used were specially manufactured for these experiments. Whether the excellence could have been retained had 100 tons been ordered is very doubtful, and the experiments would certainly have turned out less brilliantly. Careful working of bridge material cannot be counted on, as it is impossible to station a controller behind each workman.

Herr Intze explained that, in spite of the experience and experiments of Herren Petersen and Offergeld, his views (previously stated) remained unchanged, and that they had, indeed, received fresh confirmation from some experiments which, by the courtesy of the management, he had been enabled to make officially for two new bridges recently erected at Königsberg. These experiments confirmed the excellent qualities of many kinds of steel, which were, further, maintained throughout the construction, as well as in the test pieces—a result which it was well known had not been attained in the hard steel experimented on by Harkor for the Dutch bridges.

The Königsberg bridges were constructed mainly of mild steel. About sixty experiments with test pieces were made with plates, angle iron I iron, and rivet iron, yielding an average breaking strength of 49.5 kg. per square mm. (31.2 tons per square inch), a limit of elasticity 32.4 kg. per square mm. (20.4 tons per square inch), an extension of 26.9 per cent. and a contraction of 46.5 per cent.

Some I irons, which, from the arrangement of the rolling mills, could not be easily made in mild steel, had been made in puddled steel, and gave similar results, though in somewhat lower figures. Out of four experiments they showed a breaking strength of 4.43 kg. per square mm. (27.9 tons per square inch), a limit of elasticity 28.5 (18.0 tons per square inch), extension 21.8 per cent., and contraction 23.7 per cent. An interesting comparison was made of the results of experiments for these same bridges, with other materials used in constructing them, viz., cast steel, wrought and unwrought, cast iron and wrought iron. These experiments all show the superiority of mild steel. A girder made out of plates and angle iron sustained, after the highest test load, a calculated maximum bending strain of 45 kg. per square mm. (28.3 tons per square inch); a second, rolled in one piece, 48 kg. per square mm. (30.2 tons per square inch). The further increase of the load was prevented by the side bulging of the girder (against which it had not been secured), producing tiny cracks in the rivets on which the chief strain fell. The test pieces taken from these girders had shown a breaking strength of 48 kg. per square mm. in the mean. Two test girders of puddled steel, made by riveting plates to a rolled iron girder, yielded each time a maximum bending strain of 40 kg. per square mm. (25.2 tons per square inch) at the heaviest load, which, on account of the side bulging, could not be increased, although no cracks were visible. Test pieces from these girders showed a mean breaking strength of 47.3 kg. per square mm. (29.8 tons per square inch). This shows that the agreement in the experiments made between built-up girders and test pieces of the same material is satisfactory for practical purposes, especially in the case of mild steel.

In order to ascertain how their different qualities affect wrought iron and hard and soft steel, when variously worked, especially with regard to breaking point. Herr Intze recently made about 80 experiments with seven varieties of iron and steel. Dr. Forchheimer was good enough to take upon himself the greater part of the superintendence, and to note down the results, from which Herr Intze draws the following conclusions:

1. Drilling the bars does not diminish the breaking strength, but usually increases it slightly.

2. Punching diminishes the strength in almost all kinds of material.

3. Drilling considerably diminishes the work done up to breaking point (*i.e.*, the product of the stress and extension) compared with a solid bar, especially in hard materials.

4. Punching diminishes the work done considerably more than drilling.

5. Punching succeeded by annealing again raises the work done to nearly the same point as drilling without annealing.

6. With a drilled and riveted joint, after removing the rivet heads, a marked diminution of the work done up to breaking point, as compared with a joint simply drilled, is apparent, and this diminution increases with steel as the material becomes harder. With steel of about 65 kg. per square mm. breaking point (41 tons per square inch) where the section is weakened by about 46 per cent. in a test bar 150 mm. long—*i.e.*, the holes being about 150 mm. (5.9 inches) apart in the direction of the pull—with holes of about 15 mm. diameter, and after riveting up the work done was only $\frac{1}{200}$ part of that in a similar solid bar. With a similar weakening of section in a bar 1,500 mm. long—*i.e.*, the rivets being 1.500 mm. (5 feet apart) in the direction of the pull—the work done up to breaking was only $\frac{1}{2000}$ part that of a solid bar.

7. In wrought iron, with a section reduced by 46 per cent., no diminution of the work done worth heeding takes place through riveting, beyond what is caused by drilling alone. The work done is, under equal conditions, usually five times as great as in steel, with a breaking strength of 65 square mm.

8. Reductions of section, which are caused simply by drilling, show, when varying from 20 to 50 per cent., a diminution of the work done up to breaking point, according to the amount of the reduction; and this work is much smaller with hard than with mild steel.

Herr Intze considers that in these results an explanation may be found of the fact that with very great reductions of area, such as those occurring in the joints of a steam boiler, sudden failures have been observed in quite new steel boilers. On account of the high limit of elasticity, and of strains caused in the working, it might be that deformation, when combined with unequal heating, would prove, when the weakened line of rivets was tested, to have already reached the breaking point, although in the solid plate the limit of elasticity would not have been surpassed. The very low value of work done in the much weakened lines of rivets in steel plates could only admit of a very slight deformation in the boiler, and a breakage might therefore easily occur. To meet these cases it would be very desirable to find a material whose limit of elasticity, as compared with the breaking point, was small, unless the weakness of the line of rivets could be so greatly diminished that the deformation in the whole structure must considerably overpass the limit of elasticity before the breaking point of the line of rivets was reached. The speaker suggested that, having regard to the above results, those parts of structures which were both exposed to severe tension, and weakened by rivets, might be strengthened against shocks and deformation by making as many holes as possible in the line of rivets, provided the proper net section was preserved. It would of course really be best if the same net section could be maintained throughout in any such portion, as the same strength would then be preserved throughout the whole length to resist shocks. Herr Intze concluded by expressing a hope that the union would form a committee to investigate the matter, and decide on the relative merits of iron and steel.

Herr André thanked Herr Intze for his valuable paper, although he differed from his conclusions, and then said:—Two years ago we replaced the iron shaft of a high speed steam engine by a Bessemer steel one, manufactured at a works which, for such articles, stands almost, if not quite, equal to Krupp and Bochum. Atfer two years' work the shaft broke suddenly when moving very slowly, and without any load attached (the train of rolls was not coupled). We were about to replace it with another Bessemer shaft of mild steel, when the manager of the steel works himself advised us to return to the old material if there was any risk of the shaft becoming occasionally heated while working, for, he said, strong cooling appliances were then brought at once

to bear on the shaft, which produced microscopic cracks on the surface, and these in a short time, might produce an unexpected breakage. In order to confirm this, he (the speaker) telegraphed to ten wireworks where similar engines were in use, and found that the majority employed and preferred iron. It appears, therefore, that iron shafts are again replacing the steel ones which had superseded them, for quick and heavy work, where there is any risk of heating. This was further confirmed by the foreman of an engine works on the Rhine, who stated that in two years they had had five breakages of heavy steel shafts, and had in each case replaced them with iron. In one of these steel shafts, of 400 mm. diameter (15.75 inches) a hole as large as the fist was found, and in it were two small steel balls, which had ground themselves quite round and smooth in the two years. As mild steel is even more inclined to form bubbles than hard, it seems to be, at present, even less adapted for heavy shafts and pieces.

It appeared to be as little adapted for steam boilers. The same engineer, for example, had informed him that a boiler he had constructed cracked right across the bottom when removed from the workshop to the survey yard, although great care had been taken in riveting and drilling the holes.

The constructor should remember also that "mild steel" is a very vague term; and it is necessary to ascertain where and by what process it is made. Nothing can be determined by the amount of carbon it contains, for, although one can estimate approximately, according to the carbon contained, the materials produced by a certain process at a certain works, it is impossible to compare the productions of different works, especially where different processes are adopted. For example, Thomas steel, containing 1 to 1.5 of carbon may be exceedingly soft, while Bessemer steel, containing the same amount, may be so hard that a knob occurring on a thin wire rod can hardly be rolled away.

The differences in Thomas steel itself are very great, and although he could speak very favorably of it from personal experience, there were many complaints of inequalities. If an engineer, therefore, resolves to have no mild steel, but only ingot iron, he will find the border line between the two so confused that the following definition may be looked upon as a necessary expedient: "No material capable of considerable hardening shall be called iron," and, if narrowly examined, it will be seen that a great deal of the ingot iron specified as "incapable of considerable hardening" is, nevertheless, capable of very considerable hardening under certain circumstances, such as the sudden cooling of a heated shaft. This "inconsiderable hardening" is just sufficient to shrink the surface, produce tension, small cracks, and finally breakages.

This shows that the puddling furnaces are not so entirely superseded as it has been the fashion to assert, and it has become clear that such furnaces have too rapidly diminished, as the demand for puddled bar has, of late years, frequently exceeded the supply.

One may consider that ingot iron is now preferred to cast steel for the following purposes: Rails, railway axles and shafts of similar dimensions, railway sleepers, and, above all, tires. For heavy quick running shafts, iron is in request, except for very heavy marine shafts, for which crucible steel is frequently employed. For shipbuilding, the Siemens-Martin ingot iron-plates are increasingly employed, while for boiler-plates wrought iron holds undisputed sway; for wire rods, cast steel and wrought iron are about equally in demand. There is no doubt that with improvements in the management of steel processes, especially in soft steel and ignot iron, the demand for it will increase; but it is probable that, for some time to come, the existing processes will continue rivals in the same fields.

As the refining process still exists side by side with its successor, the puddling process, so will the puddling process itself survive in company with its younger rivals the Bessemer, Martin, and Thomas systems, and, thanks to its malleability, wrought iron will long find manufacturers glad to employ it.

Herr Krohn added the following observations: We find from Herr Offergeld's experiments that several girders were spoiled by bending, which occurred either in the upper girder or in the upper portion of the web in those parts most exposed to pressure. The compression

portions of an ingot iron girder showed flaws before the breaking strength of the loaded parts had been fully attained, whilst with a girder of wrought iron a uniform stress of the whole section was attained, and therefore a relatively higher breaking-point was reached. This cir cumstance may be explained by the properties of both materials. As the breaking-point is reached the relation between deformation and strain becomes greater with mild steel than with wrought iron. As it is well known that with a breaking load the amount of the moment of rupture increases with the deformation, it follows that the risk of breakage is greater with ingot than with wrought iron. Therefore, in order to maintain a uniform stress on both the compression and tension portions of an ingot iron girder, the compression portion must be strengthened to a far greater extent than is necessary with wrought iron. It seems doubtful, and on this point Herr Offergeld's experiments offer no conclusion, whether, in spite of the extra material necessary to strengthen the compression flange of an ingot iron girder in order to attain uniform stress on the whole cross-section, a saving is not effected on the whole as against wrought iron by the attainment of a higher breaking point, and on this account we must hesitate before agreeing with Herr Offergeld's unfavorable opinion of ingot iron derived from his experiments."

Herr Petersen supplemented the remarks of Herr André as follows: "Ingot iron and cast steel are both cast, have a similar granular structure and fracture, and in these respects possess unquestionable advantages over wrought iron, which is composed of successive layers, and consequently shows defects of welding, rendering it a bad material for many purposes. When these kinds break, the difference in behavior corresponds to their difference in structure. The homogeneous material breaks quick and short, whereas wrought iron, owing to its laminated structure, breaks slowly layer by layer under the bending strain. In spite, therefore, of its lower breaking strain, wrought iron offers in many cases greater security than steel, because the breakage, instead of occurring quickly and suddenly, takes place gradually, and generally gives warning of the danger by a harmless tear in the outside layer."

He had previously shown that unequal heating and careless working were apt to produce small cracks and flaws, as well as internal tension, in homogeneous materials, and these diminished the strength and prepared the way for breakages. Striking examples of this occurred in a large rail rolling mills with some cast steel crank shafts, which, after being only a short time in use, showed such serious flaws and cracks on the journals, brought on by one-sided heating while working, that they were changed for wrought iron.

It is well known that various difficulties occur in casting thick steel ingots, and it is even more frequent to have a porous casting in mild than in hard steel. If steel ingots have incomplete, hollow, or porous spots, these do not become welded together by further heating and working, but after being rolled thin they retain their porosity, as unwelded spots are retained in wrought iron. As these porous places are generally in the center of the ingot, the round bars, piston rods, and axles made of it have also usually an internal weakness, which it is difficult to set right in the working, and which may cause breakages in the future. Thus the plunger rod of a subterranean pumping engine, on being tested with water up to 20 atm., was shown to be hollow in its whole length, and water burst out of the cleft at the end of the rod. The following accident with the piston-rod of a pumping engine occurred at a Westphalian coalpit. The piston-rod in question belonged to a single-acting Cornish beam engine, with a cylinder diameter of 2 meters (6.56 feet) and a stroke of 4 meters (13.12) feet. The effective steam pressure was 4.5 atm., the vacuum about 600 mm. (23.6 inches), so that the net effective pressure on the piston was 5.3 atm., amounting altogether to 164,000 kg. (160 tons). The diameter of the piston rod was 250 mm. (9.84 inches). The break occurred at the beginning of the descent, so that 3½ meters of the stroke (11.5 feet) had yet to be accomplished. Falling from this height, the piston struck the bottom of the cylinder and smashed with it the valve boxes and all the principal parts of the engine. The

breaking strain of the piston amounted in the full transverse section only to about 3.1 kg. per square mm. (2.2 tons per square inch), and in the hollow place, where about 12 square mm. were lost, to about 4.5 kg. per square mm. (9.8 tons per sq. inch). A lead casting the size of the fist was taken out of this hole. These examples are not meant to detract from the valuable qualities of cast steel, but merely to point out those weaknesses in it which must be guarded against in practice.

VARIOUS METHODS OF DETERMINING DIMENSIONS.

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Selected Papers of the Institution of Civil Engineers.

II.

VII. Lippold's Method.

Whereas the methods hitherto mentioned leave it unexplained why by variable loads fracture is produced more easily than by a static load, engineer Lippold of Wiesbaden gives Wöhler's laws the following form:* "In order to fracture a piece, a certain amount of work is necessary, and this may be accumulated in the material at once, as well as by repeated intermittent loads. These loads, however, must recur instantaneously, or within so short a time that vibrations are produced." It follows that only through the occurrence of vibrations can extension, and with it stress and work, equal to what will overcome the statical breaking strength, be produced by a load lower than the statical breaking load.

Importance is attached to repetitions of the load only in so far as by these the limit of elasticity can be brought up nearly to the limit of fracture, in which case the relations depending on the proportionality of stress and extension are approximately applicable up to the point of fracture. In conformity with the preceding interpretation of Wöhler's law, Lippold, in determining the admissible stress, starts from the following rule: "On no member of a structure shall more work be performed by the fixed and live load than would be done by a weight slowly increasing from nothing up to the amount of the static load considered admissible." If for a piece subjected to tension or compression l denote the original length, F the sectional area, x the momentary extension or compression, E the modulus of elasticity, the piece tries to regain its original condition with a force

$$(a) \qquad X=\frac{FE}{l}x=\frac{x}{a}.$$

A further extension by the amount dx may be produced by the work $X\,dx$, and the extension of the piece from 0 to x requires the work

$$(b) \qquad \int_0^x X\,dx=\frac{x^2}{2a}=\frac{Xx}{2}=\frac{aX^2}{2}.$$

If the load increases gradually from nil up to the admissible static load $R=Fb_r$ the work done is spent only in overcoming the elastic force, and the work accumulated in the piece is by (*b*)

$$(c) \qquad A=\frac{aR^2}{2}=\frac{a}{2}(Fb_r)^2.$$

According to the above rule more work than this must not be put into the piece (in other words, the potential energy corresponding to the elastic force must not exceed this value.)

Let there be equilibrium at a given moment between the load P acting on the piece and the elastic force. Then the piece* contains the work $\frac{aP^2}{2}$, the alteration of length according to (*a*) is $\lambda=aP$. Now let a new load Q, acting in the same sense as P, be suddenly added; then the load exceeds the resistance, a part of the work of Q is transformed into kinetic energy (*vis viva*), which,

* H. Lippold. "Die Inanspruchnahme von Eisen und Stahl mit Rucksicht auf bewegte Last."

*P may also have been suddenly applied. In this case the alteration of length would, in the first instance, have been greater than λ, vibrations about the position of equilibrium λ take place; but when it is attained only the energy $\frac{aP^2}{2}$ remains behind in the piece, the rest has been principally converted into heat.

however, is gradually expended in overcoming the increasing resistance. At that moment, when no more kinetic energy remains and the greatest alteration of length $\lambda+\lambda'$ has been attained, the work done by the loads—apart from other applications (heat)—must be equal to the work of the elastic force overcome. The latter work by (b) amounts to $\frac{(\lambda'+\lambda)^2}{2a}$, so that

$$(d) \qquad \frac{aP^2}{2}+(P+Q)\lambda'=\frac{(\lambda'+\lambda)^2}{2a}$$

and hence with reference to $\lambda=aP$

$$(e) \qquad \lambda'=2aQ.$$

The new alteration of length is accordingly independent of that previously existing, and twice as great as with a gradually applied load. If now the total work spent on the piece is not to exceed the value (c), there follows from (d)

$$(f) \qquad \frac{aP^2}{2}+(P+Q)2aQ=\frac{a}{2}(Fb_r)^2,$$

and hence the requisite sectional area

$$(f) \qquad F=\frac{P+2Q}{b_r}.$$

Suppose that equilibrium exists again between a load P acting on the piece and the elastic force. Momentary alteration of length λ, work accumulated in piece $\frac{aP^2}{2}$. Suddenly a load $Q>P$, acting in the opposite sense to the latter, is applied, so that the alteration of length λ ceases, and one in the opposite sense $\lambda'-\lambda$ is produced. In neutralizing λ the force $Q-P$ and the elastic force act in the same sense, resistance only beginning with the alteration of length $\lambda'-\lambda$ in the opposite direction; and neglecting other applications of the work

$$(g) \qquad \frac{aP^2}{2}+(Q-P)\lambda'=\frac{(\lambda'-\lambda)^2}{2a}.$$

(As the original length of zero of the elastic force is approached, the potential energy $\frac{aP^2}{2}$ is converted into kinetic, and this, as well as the additional work $(Q-P)\lambda'$ coming from an external source, are, when the zero is passed, again transformed into potential energy, the value of which at the distance $\lambda'-\lambda$ from the zero is $\frac{(\lambda'-\lambda)^2}{2a}$).

As in the first case, equation (g), taken in conjunction with $\lambda=aP$, gives

$$(e) \qquad \lambda'=2aQ.$$

Here also the total alteration of length resulting from Q is independent of that previously existing, and twice as great as with a gradually applied load.

If, again, the work spent on the piece is not to exceed the value (c), then follows with regard to (e)

$$(h) \qquad \frac{aP^2}{2}+(Q-P)2aQ=\frac{a}{2}(Fb_r)^2,$$

and hence the requisite sectional area

$$(i) \qquad F=\frac{2Q-P}{b_r}.$$

If, now, a member of a bridge has to be calculated, equilibrium may be supposed established, not only after the action of the fixed load, but after every straining action. If, then, a new load be suddenly applied, the preceding formulæ are applicable. In calculating the sectional area, however, that case must be selected which gives the greatest value of F. Accordingly we obtain the necessary section and the admissible stress per unit of area:

For tension or compression only from (f), $P+Q=\max B$, $P=\min B$

$$F=\frac{2\max B-\min B}{b_r} \quad . \quad . \quad . \quad . \quad (51)$$

for alternate tension and compression from (i) where $Q-P=\max B$, $P=\max B'$

$$F=\frac{2\max B+\max B'}{b_r} \quad . \quad . \quad . \quad (52)$$

and with regard to (1) and (2) in both cases

$$b=\frac{\max B}{F}=\frac{b_r}{2-\varphi} \quad . \quad . \quad . \quad (53)$$

in these formulæ Lippold substitutes for wrought iron the value $b_r=1{,}300$, for unhardened cast steel $b_r=2{,}400$ per square centimeter.

Formula (53) agrees for tension only or compression only with Ritter's (45), in which $K=2$

In Lippold's very remarkable work views are put forward and developed which, previous to Wöhler's labors, had many supporters, and the correctness of which cannot be disputed. The question

is, however, whether this view of the subject is not one-sided, whether the destruction of the material is solely, or even mainly, due to the causes indicated.

If that be the case, then, Wöhler's law and results would lose much of their significance, as they are unnecessary for the development of the formulæ and numerical values given.

It is certainly not creditable that Lippold's work has remained almost unnoticed in Germany, especially on the part of those to whom the management of technical experiments is entrusted. The experiments hitherto made leave no doubt as to the general law, but only as to the causes of it.

Although every one is at present free to choose whether he will accept a theoretical explanation or simply remain contented with the experimental results, it is most certain from Lippold's theory, that the use of a constant coefficient of strength for determining the dimensions of engineering structures is totally indefensible.

VIII.—Clericetti's Equations.

The latest paper on the application of Wöhler's experiments is by Professor Clericetti of the Technical Institute of Milan.* Clericetti arrives in the first instance at the same conclusion as Lippold, but subsequently investigates separately the influence of repetitions of the load.

A sudden application of a load to a piece causes temporarily twice the extension (VII.), and therefore twice the increase of stress due to the same load gradually applied. This applies in the first instance to stresses within the limit of elasticity, as, however, the latter, by being exceeded, may be brought up nearly to the limit of fracture, Clericetti considers that a sudden load should be treated even until fracture occurs, as a quiescent load of twice the magnitude. As a further test, for a piece having a unit of sectional area, and to which the stress due to fixed load c, the difference of stress in the same sense d, and a statical breaking strength, t, apply, the formula is given

$$(a) \qquad c+2d=t$$

The stress at the moment of fracture by the ordinary method would be

$$(b) \qquad c+d=a$$

so that the ultimate working strength for a load quiescent only as to one portion c is

$$(c) \qquad a=\frac{c+t}{2}.$$

This formula agrees very well with Wöhler's results, as the following comparison shows:

For t=1,100 (compare IV.) and c=	0	250	400	600	1,100
by Wöhler a=	500	700	800	900	1,100
"formula (c) a=	550	675	750	850	1,100

It must, however, be remembered that in these experiments fracture occurred, not after a few applications of load, but only after 40,000,000 and more; while Kirkaldy found that with a sudden application the breaking weight varied for different kinds of iron from 75.2 to 90.4 per cent., on an average 81 per cent.* of that required with a gradual application.

Lippold ascribes this deviation of 50 per cent. to the circumstance that the loads had not sufficient time to produce the full extension and with it the full stress, the energy not used in overcoming the resistance of the piece being converted into heat.

Formula (a) is distinguished from that with which Gerber starts (I (a))

$$c+\tau d=t$$

only by the choice of the coefficient τ, which Gerber determines from experimental results. In fixing the admissible stress Clercietti proceeds as follows:

Repeated Loads in one sense.—Let B_0, B_1, denote respectively the fixed and live loads max $B=B_0+B_1$, m a factor of safety, u the primitive strength, then Clericetti writes

$$F=\frac{B_0+2B_1}{u}, m=\frac{2\max B-B_0}{u}\cdot m \quad . \quad (54)$$

According to the usual method the stress per unit of area, and with regard to (1) is

$$b=\frac{\max b}{F}=\frac{B_0+2B_1}{B_0+B_1}\frac{u}{m}=\frac{1}{2-\varphi_0}\frac{u}{m}. \quad (55)$$

If the load is in the same sense on the whole, moving loads in opposite senses

*C. Clericetti, "Sulla determinazione dei coefficienti di sferzo specifico dietro le esperienze di Wöhler," Politecnico, 1881.

*Von Kaven's "Collectaneen," Zeitschrift des hannöv. Arch. u. Ing. Vereins. 1868.

may still occur. Clericetti would apply the preceding formulæ to this case also.

Particulars are not given; but it appears that then φ should be substituted for φ_0 (which is correct when $B_0 = \min B$), whence generally

$$b = \frac{1}{2-\varphi}\frac{u}{m} \quad . \quad . \quad . \quad (56)$$

The formula differs from Lippold's (53), in so far as in the latter $\frac{t}{m} = b_r$ takes the place of $\frac{u}{m}$. With a suitable choice of constants, both these formulæ, as well as Ritter's (45) lead to equal values of b.

Repeated Loads in opposite senses.—Let B_0, B_1, B_2, denote the numerical values of the fixed load and the extreme live load. On the assumption of the sudden application of the live load the actual stress varies according to Clericetti—when B_0 B_1 act in the same sense—between

$$\pm\frac{B_0+2B_1}{F} \text{ and } \mp\frac{2B_2}{F},$$

when B_0, B_2 denote loads in the same sense

$$\pm\frac{B_0+2B_2}{F} \text{ and } \mp\frac{2B_1}{F};$$

hence in both cases the difference of stress would be

$$(d) \qquad d = \frac{B_0+2B_1+2B_2}{F};$$

and s being the vibration strength, Clericetti makes the sectional area

$$F = \frac{B_0+2B_1+2B_2}{2s}m \quad . \quad . \quad . \quad (57)$$

where $m\,d = 2\,s$ has been introduced. As by (19) and (20) $B_1+B_2 = \max B + \max B_1$ there follows also

$$F = \frac{\max B + \max B_1 + \frac{1}{2}B_0}{s}m \quad . \quad . \quad (58)$$

and having regard to (2) the stress per unit of area is

$$b = \frac{\max B}{B_1+B_2+\frac{1}{2}B_0}\frac{s}{m} = \frac{1}{1-\varphi\pm\frac{1}{2}\varphi_0}\frac{s}{m} \quad (59)$$

Herein the upper or lower sign is applicable to φ_0, according as the fixed load is of the same or opposite kind as the upper limiting load, that is, always that sign which will make the quantity $\pm\frac{\varphi_0}{2}$ positive.

Numerical Values.—Clericetti takes the following values of t, u, s, as averages from Wöhler's experiments, for iron 3,800, 2,450, 1,385, for steel 6,800, 3,400, 2,000, adopts the factor of safety $m=2$, and thus obtains, in the case of iron, for tension only or compression only

$$F = \frac{B_0+2B_1}{1{,}250} \quad . \quad . \quad . \quad . \quad . \quad (60)$$

$$b = 1{,}250\frac{B_0+B_1}{B_1+2B_1} = \frac{1{,}250}{2-\varphi_0} \quad . \quad . \quad (61)$$

For alternate tension and compression

$$F = \frac{B_1+B_2+\frac{1}{2}B_0}{650} \quad . \quad . \quad (62)$$

$$b = 650\frac{\max B}{\frac{1}{2}B_0+B_1+B_2} = \frac{650}{1-\varphi\pm\frac{1}{2}\varphi_0} \quad (63)$$

According to the principles of the preceding method itself, for alternate tension and compression, the actual stress should not be assumed as above, but as varying between

$$\pm\frac{B_0+2B_1}{F} \text{ and } \pm\frac{B_0-2B_2}{F},$$

and $\pm\frac{B_0+2B_2}{F}$ and $\pm\frac{B_0-2B_1}{F}$,

respectively. (*Vide* also X).

Hence would follow, in a way similar to the preceding

$$(e) \qquad d = \frac{B_1+B_2}{F}2$$

$$b = \frac{1}{1-\varphi}\frac{s}{m} \quad . \quad . \quad . \quad . \quad (64)$$

Formulæ (56) (64) give, then, for iron, with tension or compression only,

$$b = \frac{1{,}250}{2-\varphi} \quad . \quad . \quad . \quad . \quad (65)$$

and with alternations of tension and compression, on account of $s=1{,}385$ and $m=2$,

$$b = \frac{700}{1-\varphi} \quad . \quad . \quad . \quad . \quad . \quad (66)$$

For $\varphi=0$, $\varphi_0=0$, equal values of b should result from the formulas for tension and compression only, and from those for alternate tension and compres-

sion. The way in which u and s are introduced into the above formulas can, however, scarcely be justified, and, after what has been said of a at the commencement, is surprising.

Equation (64), with a suitable choice of constants, gives the same results as a rule followed by American engineers previous to Wöhler's experiments, according to which for alternate tension and compression.

$$F=\frac{\max B+\max B_1}{c} \quad . \quad . \quad . \quad (67)$$

where c denotes the ordinary stress for tension alone. The stress per unit of area would be

$$b=\frac{\max B}{F}=\frac{c}{1-\varphi} \quad . \quad . \quad . \quad . \quad . \quad (68)$$

this formula coincides with (64) for $c=\frac{u}{m}$.

IX.—Examples.

For a better comprehension of the various methods of determining dimensions some examples shall be calculated.

As almost all authors have left liability to buckling unnoticed, it shall remain excluded here. It may be taken into account in a way which is for all methods analogous to that described in the author's previous communication for the Launhardt and Weyrauch system.* The latter gave for tension or compression only without liability to buckling

$$b=v(1+m\varphi); \quad F=\frac{\max B}{v(1+m\varphi)}; \quad . \quad . \quad (69)$$

and for alternate tension and compression

$$b=v(1+n\varphi); \quad F=\frac{\max B}{v(1+n\varphi)} \quad . \quad . \quad (70)$$

On the authority of Wöhler's experiments for iron the values were adopted $v=700$, $m=n=\frac{1}{2}$, whence generally

$$b=350(2+\varphi); \quad F=\frac{\max B}{350(2+\varphi)} \quad . \quad . \quad (71)$$

As, however, the choice of constants depends on the constructive material, the object of the structure and experience of the designer, no great weight was attached to the numerical values, and, for example, the less favorable data

$$b=320(2+\varphi); \quad F=\frac{\max B}{320(2+\varphi)} \quad . \quad . \quad (72)$$

were also given.

* Minutes of Proceedings Inst. C.E., vol. lxiii., p. 290.

Example 1.—For the boom of a girder-bridge which is always in tension (or always in compression), the load varies between the maximum value max B=30,000 and the minimum value, due to the fixed load only, min B=10,000 kilograms. The requisite net sectional area is to be determined.

(1) By the old method with $b=700$ there follows:

$$F=\frac{30{,}000}{700}=42.86 \text{ square centimeters.}$$

(2) By Gerber's method with $B_c=10{,}000$, $B_v=20{,}000$ from (8)–(10).

$$\varphi=\frac{10{,}000}{1.5\times 20{,}000}=\tfrac{1}{3}.$$

$$\delta=\tfrac{1}{2}(3+\sqrt{16\times\tfrac{1}{3}+16\times\tfrac{1}{3}+13})\times 1.871.$$

$$F=\frac{1.5\times 1.871\times 20{,}000}{1{,}600}$$

$$=35.08 \text{ square centimeters.}$$

(3) By Schaffer's method with $B_0=10{,}000$, $B_1=20{,}000$, $B_2=0$ from (23)–(25).

$$\xi=\frac{1.5\times 20{,}000}{1.5\times 20{,}000+10{,}000}=\tfrac{3}{4}.$$

$$\frac{a}{m}=\frac{-3\times\frac{3}{4}+\sqrt{13\times\frac{9}{16}-16\times\frac{3}{4}+16}}{(2-\frac{3}{4})^2}1{,}600$$

$$=1{,}140.$$

$$F=\frac{1.5\times 20{,}000+10{,}000}{1{,}140}$$

$$=35.08 \text{ square centimeters.}$$

(4) By Winkler's method with $B_0=10{,}000$, $B_1=20{,}000$, $B_2=0$ from (32).

$$F=\frac{10{,}000}{1{,}400}+\frac{20{,}000}{590}$$

$$=41.04 \text{ square centimeters.}$$

(5) By Seefehlner's method with $\varphi=10{,}000:30{,}000=\frac{1}{3}$ from (44).

$$F=\frac{4-\frac{1.6}{3}}{2+\frac{1}{3}}\cdot\frac{30{,}000}{1{,}200}$$

$$=37.14 \text{ square centimeters.}$$

(6) By Launhardt and Weyrauch's method with $\varphi=\frac{1}{3}$ from (71).

$$F=\frac{30{,}000}{350(1+\frac{1}{3})}=36.73 \text{ square centimeters.}$$

(7) By Ritter's method with $\varphi=\frac{1}{3}$ from (48).

$$F=\frac{30{,}000(2-\frac{1}{3})}{1{,}200}$$

$$=41.67 \text{ square centimeters.}$$

(8) By Lippold's method from (51).

$$F=\frac{2\times 30{,}000-10{,}000}{1{,}300}$$

$=38.46$ square centimeters.

(9) By Clericetti's method, with $B_0=10{,}000$, $B_1=20{,}000$ from (60).

$$F=\frac{10{,}000+2\times 20{,}000}{1{,}250}$$

$=40.00$ square centimeters.

Example 2.—For a member of a bridge always in tension (or always in compression) the greatest load max $B=30{,}000$, the smallest min $B=10{,}000$, as above, but the fixed load $B_0=20{,}000$ kilograms. The net sectional area is to be determined.

(1) By the old method as above, $F=42.86$ square centimeters.

(2) According to Gerber with $B_c=20{,}000$, and $B_v=10{,}000$.

$$\varphi_1=\frac{20{,}000}{1.5\times 10{,}000}=\frac{4}{3}.$$

$$\delta_1=\tfrac{1}{4}\left(3+\sqrt{16\times\frac{16}{9}+16\times\frac{4}{3}+13}\right)=2.731.$$

$$F_1=\frac{1.5\times 2.731\times 10{,}000}{1{,}600}=25.60,$$

then with $B_c=20{,}000$, $B_v=-10{,}000$.

$$\varphi_2=\frac{20{,}000}{1.5\times 10{,}000}=-\frac{4}{3}.$$

$$\delta_2=\tfrac{1}{4}\left(3+\sqrt{16\times\frac{16}{9}-16\times\frac{4}{3}+13}\right)=1.871.$$

$$F_2=\frac{1.5\times 1.871=10{,}000}{1{,}600}=17.54,$$

and together

$F=25.60+17.54=43.14$

square centimeters.

(3) According to Schaffer with $B_0=20{,}000$, $B_1=10{,}000$, $B^2=10{,}000$ from (23)–(25).

$$\xi=\frac{1.5(10{,}000+10{,}1000)}{1.5\times 10{,}000+20{,}000}=\frac{6}{7}.$$

$$\frac{a}{m}=\frac{-3\times\frac{6}{7}+\sqrt{13\times\frac{36}{49}-16\times\frac{6}{7}+16}}{(2-\frac{6}{7})^2}1{,}600$$

$=1{,}055.$

$$F=\frac{1.5\times 10{,}000+20{,}000}{1{,}055}$$

$=33.18$ square centimeters.

(4) According to Winkler with $B_0=20{,}000$, $B_1=10{,}000$, $B_2=10{,}000$, from (32).

$$F=\frac{20{,}000}{1{,}400}+\frac{10{,}000}{590}+\frac{10{,}000}{1{,}300}$$

$=38.93$ square centimeters.

(5) According to Seefehlner as above

$F=37.14$ sq. cent.

(6) " " Launhardt and Weyrauch

$F=36.73$ sq. cent.

(7) " " Ritter as above

$F=41.67$ "

(8) " " Lippold as above

$F=38.46$ "

(9) " " Clericetti with $\varphi=\frac{1}{3}$

$F=40.00$ sq. cent.

Example 3.—A piece sustains a maximum tensile load of max $B=40{,}000$ and a maximum compression of max $B_1=20{,}000$, while the fixed load in tension is $B^0=10{,}000$ kilograms. The net sectional area is to be determined

(1) According to the old method, with $b=700$

$$F=\frac{40.000}{700}=57.14 \text{ square centimeters.}$$

(2) According to Gerber from (8)–(10) with $B_c=10{,}000$, $B_v=30{,}000$.

$$\varphi_1=\frac{10{,}000}{1.5\times 30{,}000}=\frac{2}{9}.$$

$$\delta_1=\tfrac{1}{4}\left(3+\sqrt{16\times\tfrac{4}{81}+16\times\tfrac{2}{9}+13}\right)=1.791.$$

$$F_1=\frac{1.5\times 1.791\times 30{,}000}{1{,}600}=50.37.$$

Then with $B_c=10{,}000$, $B_v=-30{,}000$.

$$\varphi_2=-\frac{10{,}000}{1.5\times 30{,}000}=-\frac{2}{9}.$$

$$\delta_2=\tfrac{1}{4}\left(3+\sqrt{16\times\tfrac{4}{81}-16\times\tfrac{2}{9}+13}\right)=1.550.$$

$$F_2=\frac{1.5\times 1.550\times 30{,}000}{1{,}600}=43.59;$$

and together

$F=50.37+43.59=93.96$

square centimeters.

(3) According to Schaffer with $B_0=10{,}000$, $B_1=30{,}000$, $B_2=30{,}000$ from (23)–(25).

$$\xi=\frac{1.5(30{,}000+30{,}000)}{1.5\times 30{,}000+10{,}000}=\frac{18}{11}.$$

$$\frac{a}{m}=\frac{-3\times\frac{18}{11}+\sqrt{13\times\frac{324}{121}-16\times\frac{18}{11}+16}}{\left(2-\frac{18}{11}\right)^2}$$

$1{,}600=64$

$$F=\frac{1.5\times 30{,}000+10{,}000}{648}$$
$$=84.88 \text{ square centimeters.}$$

(4) According to Winkler with $B_0=10{,}000$, $B_1=30{,}000$, $B_2=30{,}000$ from (32)

$$F=\frac{10{,}000}{1{,}400}+\frac{30{,}000}{590}+\frac{30{,}000}{1{,}300}$$
$$=81.07 \text{ square centimeters.}$$

(5) According to Seefehlner with $\varphi=-20{,}000:40{,}000=-\frac{1}{2}$ from (44)

$$F=\frac{4+\frac{1.6}{2}}{2-\frac{1}{2}}\frac{40{,}000}{1{,}200}$$
$$=106.67 \text{ square centimeters.}$$

(6) According to Launhardt and Weyrauch with $\varphi=-\frac{1}{2}$ from (71)

$$F=\frac{40{,}000}{350(1-\frac{1}{2})}=76.19 \text{ square centimeters.}$$

(7) According to Ritter with $\varphi=-\frac{1}{2}$ from (50)

$$F=\frac{40{,}000\times 0.5}{(1+0.5-\sqrt{1+0.5^2})600}$$
$$=87.26 \text{ square centimeters.}$$

(8) According to Lippold from (52)

$$F=\frac{2\times 40{,}000+20{,}000}{1{,}300}$$
$$=76.92 \text{ square centimeters.}$$

(9) According to Clericetti with $B_0=10{,}000$, $B_1=30{,}000$, $B_2=30{,}000$ from (62).

$$F=\frac{30{,}000+30{,}000+5{,}000}{650}$$
$$=100.00 \text{ square centimeters.}$$

Example 4.—A piece sustains a maximum tensile load max B=40,000, and a maximum compressive load max B′=20,000, which latter, however, at the same time, represents the fixed load. The net sectional area is to be determined.

(1) According to the old method as above, F=57.14 square centimeters.

(2) According to Gerber with $B_0=-20{,}000$, $B_0=60{,}000$ from (8)–(10)

$$\varphi=-\frac{20{,}000}{1.5\times 60{,}000}=-\frac{2}{9}.$$

$$\delta=\tfrac{1}{4}\left(3+\sqrt{16\times\frac{4}{81}-16\times\frac{2}{9}+13}\right)=1.550.$$

$$F=\frac{1.5\times 1.550\times 60{,}000}{1{,}600}$$
$$=87.19 \text{ square centimeters.}$$

(3) According to Schaffer with $B_0=20{,}000$, $B_1=60{,}000$, $B'=0$ from (23)–(25)

$$\xi=\frac{1.5\times 60{,}000}{1.5\times 60{,}000-20{,}000}=\frac{9}{7}.$$

$$\frac{a}{m}=\frac{-3\times\frac{9}{7}+\sqrt{13\times\frac{81}{49}-16\frac{9}{7}+16}}{\left(2-\frac{9}{7}\right)^2}\ 1{,}600$$
$$=803.$$

$$F=\frac{1.5\times 60{,}000-20{,}000}{803}$$
$$=87.18 \text{ square centimeters.}$$

(4) According to Winkler with $B_0=20{,}000$, $B_1=60{,}000$, $B_2=0$ from (32).

$$F=\frac{20{,}000}{1{,}400}+\frac{60{,}000}{590}$$
$$=87.41 \text{ square centimeters.}$$

(5) According to Seefehlner as above
F=106.67 square centimeters.

(6) According to Launhardt and Weyrauch as above
F=76.19 square centimeters.

(7) According to Ritter as above
F=87.26 square centimeters.

(8) According to Lippold as above
F=76.92 square centimeters.

(9) According to Clericetti with $B_0=20{,}000$, $B_1=60{,}000$, $B_2=0$ from (62).

$$F=\frac{60{,}000\times 10.000}{650}$$
107.69 square centimeters.

X. Tables.

The following tables are intended to show in a concise form how the admissible stress per square centimeter for iron bridges varies according to the various methods of determining dimensions previously demonstrated. As hitherto, for tension or compression only

$$\varphi=\frac{\min B}{\max B} \qquad \varphi_0=\frac{B_0}{\max B},$$

and for alternate tension and compression

$$\varphi=-\frac{\max B'}{\max B} \qquad \varphi_0=\pm\frac{B_0}{\max B}.$$

In the latter case the upper or lower sign is applicable according as the fixed load (numerical value B_0) is in the same or opposite sense as the higher limiting load (numerical value max B).

TABLE A.—FOR TENSION OR COMPRESSION ONLY.

Method.	Formula.	φ_0	$\varphi=0$.	$\varphi=\frac{1}{4}$.	$\varphi=\frac{1}{2}$.	$\varphi=\frac{3}{4}$.	$\varphi=1$.
Old.....	$b=c$	*ad lib.*	700	700	700	700	700
Mainz Bridge...	(74)	φ	533	640	800	1,067	1,600
Gerber.....	(13)	φ	646	794	998	1,271	1,600
	(12)	$\frac{\varphi+1}{2}$	584	670	741	1,333	1,600
	(13)	1	703	891	1,140	1,402	1,600
Schäffer.....	(29)	φ	646	794	998	1,271	1,600
	(29)	$\frac{\varphi+1}{2}$	680	845	1,067	1,333	1,600
	(29)	1	704	892	1,140	1,402	1,600
Winkler.....	(38)	φ	592	692	832	1,044	1,400
	(38)	$\frac{\varphi+1}{2}$	632	733	871	1,074	1,400
	(38)	1	678	779	914	1,106	1,400
Seefehlner.....	(43)	*ad lib.*	680	750	937	1,178	1,500
Launhardt & Weyrauch..	(71)	*ad lib.*	700	787	875	962	1,050
	(72)	"	640	720	800	880	960
Ritter.....	(47)	*ad lib.*	600	686	800	960	1,200
Lippold.....	(53)	*ad lib.*	650	743	867	1,040	1,300
Clericetti.....	(61)	φ	625	714	833	1,000	1,250

In table A, φ_0 may vary from φ (B_0= min B) to 1 (B_0=max B), for instance for the booms of girder bridges

$$\varphi=\varphi_0=\frac{\text{min B}}{\text{max B}}=\frac{p}{q} \quad . \quad . \quad . \quad . \quad (73)$$

where p is the weight of the girder itself, and $q=p+z$ the total load on the latter per unit of length. Up to spans of 100 meters φ may attain about the value $\frac{1}{2}$. For comparison the values are also added of

$$b=\frac{p+z}{p+3z}1{,}600=\frac{1{,}600}{3-2\varphi} \quad . \quad . \quad (74)$$

which are those assumed to be admissible, as early as the year 1863, by Gerber, in calculating the Mainz railway bridge.*

In Table B, φ_0 may vary: (1) when the fixed load is of the same kind as the upper limiting load, from 0 to 1, and (2) when the fixed load is of the opposite kind to the upper limiting load from 0 to φ.

*Gerber in Zeitschrift des Vereins deutscher Ingenieure, 1865.

From both the preceding tables the inaccuracy of Gerber's division of the difference of stress (I) will be apparent, as it is impossible that the admissible stress b should vary with φ_0 in the irregular manner shown.

The remarkable values obtained by Clericetti in Table B are due to the assumption mentioned towards the end of VIII. with regard to the actual stresses with a suddenly applied load. If this assumption is corrected aud formula (66) accepted, the values given in Table B as "American" are the result (compare VIII.).

If two pieces, subjected only to tension or only to compression, sustain equal maximum loads, max B, and equal minimum loads, min B, according to Table A and examples (1), (2), (IX.), the formulæ of Schaffer and Winkler give the mallest sectional area for that piece which sustains the greatest fixed load. The same remark applies to Gerber, in so far as the influence of the division of the

TABLE B.—ALTERNATE TENSION AND COMPRESSION.

Method.	Formula.	φ_o.	$\varphi=0$.	$\varphi=-\frac{1}{3}$.	$\varphi=-\frac{1}{2}$.	$\varphi=-\frac{2}{3}$.	$\varphi=-1$.
Old	$b=c$	*ad lib.*	700	700	700	700	700
Gerber.....	(15)	φ	646	538	459	399	351
	(14)	$\frac{\varphi}{2}$	646	513	424	361	315
	(14)	0	646	517	431	369	323
	(14)	$\frac{1}{2}$	584	486	412	358	315
	(15)	1	703	569	474	404	351
Schäffer.....	(29)	φ	646	538	459	399	351
	(29)	$\frac{\varphi}{2}$	646	544	464	403	354
	(29)	0	646	550	469	406	356
	(29)	$\frac{1}{2}$	680	563	473	405	354
	(29)	1	704	573	474	404	351
Winkler.....	(38)	φ	592	518	460	413	376
	(38)	$\frac{\varphi}{2}$	592	525	471	428	391
	(38)	0	592	556	523	495	408
	(38)	$\frac{1}{2}$	632	591	555	522	427
	(38)	1	678	636	590	553	448
Seefehlner.....	(43)	*ad lib.*	600	477	375	289	214
Launhardt & Weyrauch..	(71)	*ad lib.*	700	612	525	437	350
	(72)	"	640	560	480	400	320
Ritter.....	(49)	*ad lib.*	600	526	458	400	321
Lippold.....	(53)	*ad lib.*	650	578	520	478	433
Clericetti.....	(63)	φ	650	473	371	306	260
	(63)	$\frac{\varphi}{2}$	650	495	409	335	289
	(63)	0	650	520	433	371	325
	(63)	$\frac{1}{2}$	520	433	371	325	289
	(63)	1	433	371	325	289	260
American.....	(66)	*ad lib.*	700	560	467	400	350

difference of the load previously referred to is not predominant. This is due to the fact that the live load is introduced into the calculation by the authors named, multiplied with a factor n, for the purpose of taking separately into account the influence of impact.

Of course none of the methods of calculation reviewed are intended to give a rigid law for determining dimensions, but merely as guides from which the practical engineer will deviate in one direction or another if there are reasons for so doing.

As formerly the value b=constant was taken, but with reference to particularly unfavorable conditions lower values also were adopted, so the methods reviewed assume $b=f(x, y \ldots)$, but leave free play for the recognition of any special circumstances. For calculating the parts of machinery it has latterly been thought desirable to systematically utilize Wöhler's results,* experience having led to the adoption of perfectly different admissible stresses for different ways of applying loads, which, however, in the cases of static tension, tension alternating with zero, and alternations of equal tension and compression confirmed Wöhler's ratio of 3:2:1 given by formulæ (71) (72). Undoubtedly all the new methods have their faults, but the method hitherto in use is quite indefensible.

* C. Bach: "Die Maschinenelemente, ihre Berechnung und Construction mit Rücksicht auf die neueren Versuche." Stuttgart, 1881.

SOME POINTS IN ELECTRIC LIGHTING.

By DR. JOHN HOPKINSON, F. R. S., M. Inst. C. E.

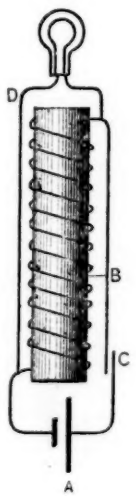
A Lecture delivered before the Institution of Civil Engineers.

ARTIFICIAL light is generally produced by raising some body to a high temperature. If the temperature of a body be greater than that of surrounding bodies it parts with some of its energy in the form of radiation. Whilst the temperature is low these radiations are not of a kind to which the eye is sensitive; they are exclusively radiations less refrangible and of greater wave-length than red light, and may be called infra red. As the temperature is increased the infra red radiations increase, but presently there are added radiations which the eye perceives as red light. As the temperature is further increased, the red light increases, and yellow, green and blue rays are successively thrown off in addition. On pushing the temperature to a still higher point, radiations of a wave-length, shorter even than violet light, are produced, to which the eye is insensitive, but which act strongly on certain chemical substances; these may be called ultra violet rays. It is thus seen that a very hot body in general throws out rays of various wave-lengths, our eyes, it so happens, being only sensitive to certain of these, viz., those not very long and not very short, and that the hotter the body the more of every kind of radiation will it throw out; but the proportion of short waves to long waves becomes vastly greater as the temperature is increased. The problem of the artificial production of light with economy of energy is the same as that of raising some body to such a temperature that it shall give as large a proportion as possible of those rays which the eye happens to be capable of feeling. For practical purposes this temperature is the highest temperature we can produce. Owing to the high temperature at which it remains solid, and to its great emissive power the radiant body used for artificial illumination is nearly always some form of carbon. In the electric current we have an agent whereby we can convert more energy of other forms into heat in a small space than in any other way; and fortunately carbon is a conductor of electricity as well as a very refractory substance.

The science of lighting by electricity very naturally divides itself into two principal parts—the methods of production of electric currents, and of conversion of the energy of those currents into heat at such a temperature as to be given off in radiations to which our eyes are sensible. There are other subordinate branches of the subject, such as the consideration of the conductors through which the electric energy is transmitted, and the measurement of the quantity of electricity passing and its potential or electric pressure. Although I shall have a word or two to say on the other branches of the subject, I propose to occupy most of the time at my disposal this evening with certain points concerning the conversion of mechanical energy into electrical energy. We know nothing as to what electricity is, and its appeals to our senses are in general less direct than those of the mechanical phenomena of matter. The laws, however, which we know to connect together those phenomena which we call electrical, are essentially mechanical in form, are closely correlated with mechanical laws, and may be most aptly illustrated by mechanical analogues. For example, the terms "potential," "current," and "resistance," with which we are becoming familiar in electricity have close analogues respectively in "head," "rate of flow," and "coefficient of friction" in the hydraulic transmission of power. Exactly as in hydraulics, head multiplied by velocity of flow is power measured in foot-pounds per second or in horse-power, so potential multiplied by current is power and is measurable in the same units. The horse-power not being a convenient electrical unit, Dr. Siemens has suggested that the electrical unit of power or volt-ampere should be called a watt: 746 watts are equal to one horse-power. Again, just as water flowing in a pipe has

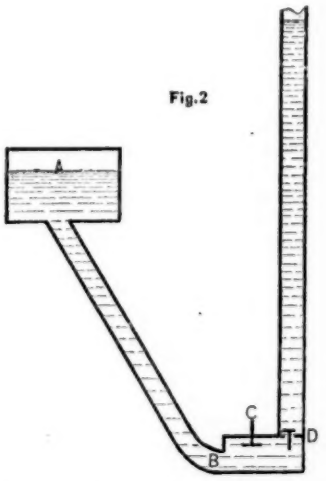
inertia and requires an expenditure of work to set it in motion, and is capable of producing disruptive effects if its motion is too suddenly arrested—as, for example, when a plug-tap is suddenly closed in a pipe through which water is flowing rapidly, so a current of electricity in a wire has inertia; to set it moving electro-motive force must work for a finite time, and if we attempt to arrest it suddenly by breaking the circuit, the electricity forces its way across the interval as a spark. Corresponding to mass and moments of inertia in mechanics we have in electricity coefficients of self-induction.

Fig.1



We will now show that an electric circuit behaves as though it had inertia. The apparatus we shall use is shown diagrammatically in Fig. 1. A current from a Sellon battery A circulates round an electro-magnet B; it can be made and broken at pleasure at C. Connected to the two extremities of the wire on the magnet is a small incandescent lamp D, lent me by Mr. Crompton, of many times the resistance of the coil. On breaking the circuit, the current in the coil, in virtue of its momentum, forces its way through the lamp, and renders it momentarily incandescent, although all con nection with the battery, which in any case would be too feeble to send sufficient current through the lamp, has ceased. Let us try the experiment, make contact, break contact. You observe the lamp lights up. Compare with the diagram Fig. 2 of the hydraulic analogue the hydraulic ram. There a current of water suddenly arrested forces a way for a portion of its quantity to a greater height than that from which it fell. A B corresponds to the electro magnet, the valve C to the contact-breaker, and D E to the lamp. There is, however, this difference between the inertia of water in a pipe and the inertia of an electric current—the inertia of the water is confined to the water, whereas the inertia of the electric

Fig.2

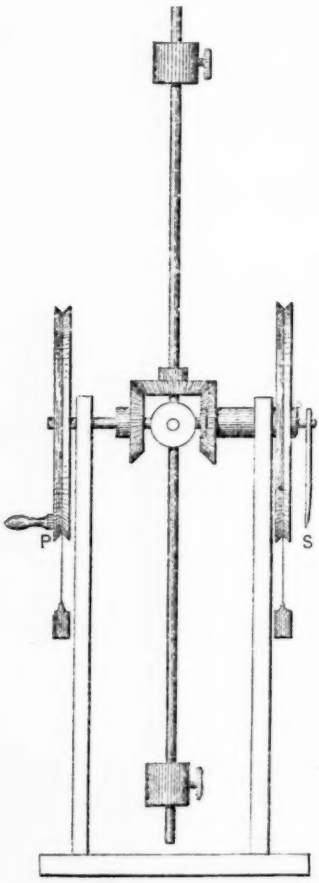


current resides in the surrounding medium. Hence arise the phenomena of induction of currents upon currents, and of magnets upon moving conductors—phenomena which have no immediate analogues in hydraulics. There is thus little difficulty to any one accustomed to the laws of rational mechanics in adapting the expression of those laws to fit electrical phenomena; indeed we may go so far as to say that the part of electrical science with which we have to deal this evening is essentially a branch of mechanics, and as such I shall endeavor to treat it.

This is neither the time nor the place for setting forth the fundamental laws of electricity, but I cannot forbear from showing you a mechanical illustration, or

set of mechanical illustrations, of the laws of electrical induction, first discovered by Faraday. I have here a model, Fig. 3, which was made to the instructions of the late Professor Clerk Maxwell, to illustrate the laws of induction. It consists of a pulley P, which I now

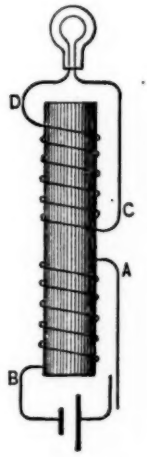
Fig. 3



turn with my hand, and which represents one electric circuit, its motion the current therein. Here is a second pulley S, representing a second electric circuit. These two pulleys are geared together by a simple differential train, such as is sometimes used for a dynamometer. The intermediate wheel of the train, however, is attached to a balanced fly-wheel, the moment of inertia of which can be varied by moving inwards or outwards these four brass weights. The resistances of the two electric circuits are represented by the friction on the pulleys of two strings, the tension of which can be varied by tightening these elastic bands. The differential train, with its fly-wheel, represents the medium, whatever it may be, between the two electric conductors. The mechanical properties of this model are of course obvious enough. Although the mathematical equations which represent the relation between one electric conductor and another in its neighborhood are the same in form as the mathematical equations which represent the mechanical connection between these two pulleys, it must not be assumed that the magnetic mechanism is completely represented by the model. We shall now see how the model illustrates the action of one electric circuit upon another. You know that Faraday discovered that if you have two closed conductors arranged near to and parallel to each other, and if you cause a current of electricity to begin to flow in the first, there will arise a temporary current in the opposite direction in the second. This pulley, marked P on the diagram, represents the primary circuit, and the pulley marked S on the diagram the secondary circuit. We cause a current to begin to flow in the primary, or turn the pulley P; an opposite current is induced in the secondary circuit, or the pulley S turns in the opposite direction to that in which we began to move the pulley P. The effect is only temporary, resistance speedily stops the current in the secondary circuit, or in the mechanical model friction the rotation of the pulley S. I now gradually stop the motion of P; the pulley S moves in the direction in which P was previously moving, just as Faraday found that the cessation of the primary current induced in the secondary circuit a current in the same direction as that which had existed in the primary. If there were a large number of convolutions or coils in the secondary circuit, but that circuit were not completed, but had an air space interrupting its continuity, an experiment with the well-known Ruhmkorff coil would show you that when the current was *suddenly*

made to cease to flow in the primary circuit, so great an electromotive force would be exerted in the secondary circuit that the electricity would leap across the space as a spark. I will now show you what corresponds to a spark with this mechanical model. The secondary pulley S shall be held by passing a thread several times round it. I gradually produce the current in the primary circuit: I will now suddenly stop this primary current: you observe that the electromotive force is sufficient to break the thread. The inductive effects of one electric circuit upon another depend not alone on the dimensions and form of the two circuits, but on the nature of the material between them. For example, if we had two parallel circular coils, their inductive effects would be very considerably enhanced by introducing a bar of iron in their common axis. We can imitate this effect by moving outwards or inwards these brass weights. In the experiment I have shown you the weights have been some distance from the axis in order to obtain considerable effect, just as in the Ruhmkorff coil an iron core is introduced within the primary circuit. I will now do what is equivalent to removing the core: I will bring the weights nearer to the axis, so that my fly-wheel shall have less moment of inertia. You observe that the inductive effects are very much less marked than they were before. With the same electro-magnet which we used before, but differently arranged, we will show what we have just illustrated—the induction of one circuit on another. Referring to Fig. 4, coil A B corresponds to wheel P; C D to wheel S; and the iron core to the fly-wheel and differential gear. The resistance of a lamp takes the place of the friction of the string on S. As we make and break the circuit you see the effect of the induced current in rendering the lamp incandescent. So far I have been illustrating the phenomena of the induction of one current upon another. I will now show on the model that a current in a single electric circuit has momentum. The secondary wheel shall be firmly held; it shall have no conductivity at all; that is, its electrical effect shall be as though it were not there. I now cause a current to begin to flow in the primary circuit, and it is obvious enough that a certain amount of work must be done to bring it up to a certain speed. The angular velocity of the fly-wheel is half that of the pulley representing the primary circuit. Now suppose that the two pulleys were connected together in such a way that they must have the same angular velocity in the same direction. This represents the coil having twice as many convolutions as it had before. A little consideration will show that I must do four times as much work to give the primary pulley the same velocity that it attained before; that is to say, that the coefficient of self-induction of a coil of wire is proportional to the square of the number of convolutions. Again, suppose that these two wheels were so geared together that they must always have equal

Fig. 4

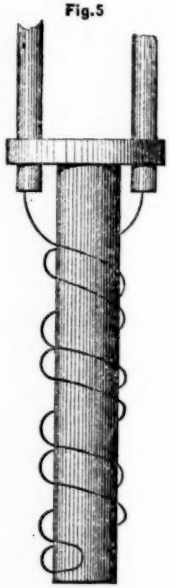


and opposite velocities, you can see that a very small amount of work must be done in order to give the primary wheel the velocity which we gave to it before. Such an arrangement of the model represents an electric circuit, the coefficient of induction of which is exceedingly small, such as the coils that are wound for standard resistances; the wire is there wound double, and the current returns upon itself, as shown in Fig. 5.

In the widest sense, the dynamo-electric machine may be defined as an apparatus for converting mechanical energy into the energy of electro-static charge,

or mechanical power into its equivalent electric current through a conductor. Under this definition would be included the electrophorus and all frictional machines; but the term is used, in a more restricted sense, for those machines which produce electric currents by the motion of conductors in a magnetic field, or by the motion of a magnetic field in the neighborhood of a conductor. The laws on which the action of such machines is based have been the subject of a series of discoveries. Oersted discovered that an electric current in a conductor exerted

Fig.5



force upon a magnet; Ampère that two conductors conveying currents generally exerted a mechanical force upon each other: Faraday discovered—what Helmholtz and Thomson subsequently proved to be the necessary consequence of the mechanical reactions between conductors conveying currents and magnets—that if a closed conductor move in a magnetic field, there will be a current induced in that conductor in one direction, if the number of lines of magnetic force passing through the conductor was increased by the movement; in the other direction if diminished. Now all dynamo-electric machines are based upon Faraday's discovery. Not only so; but however elaborate we may wish to make the analysis of the action of a dynamo-machine, Faraday's way of presenting the phenomena of electro-magnetism to the mind is in general our best point of departure. The dynamo-machine, then, essentially consists of a conductor made to move in a magnetic field. This conductor, with the external circuit, forms a closed circuit in which electric currents are induced as the number of lines of magnetic force passing through the closed circuit varies. Since, then, if the current in a closed circuit be in one direction when the number of lines of force is increasing, and in the opposite direction when they are diminishing, it is clear that the current in each part of such circuit which passes through the magnetic field must be alternating in direction, unless indeed the circuit be such that it is continually cutting more and more lines of force, always in the same direction. Since the current in the wire of the machine is alternating, so also must be the current outside the machine, unless something in the nature of a commutator be employed to reverse the connections of the internal wires in which the current is induced, and of the external circuit. We have then broadly two classes of dynamo-electric machines; the simplest, the alternating current machine, where no commutator is used; and the continuous-current machine, in which a commutator is used to change the connection of the external circuit just at the moment when the direction of the current would change. The mathematical theory of the alternate-current machine is comparatively simple. To fix ideas, I will ask you to think of the alternate-current Siemens machine, which Dr. Siemens exhibited here three weeks ago. We have there a series of magnetic fields of alternate polarity, and through these fields we have coils of wire moving; these coils constitute what is called the armature; in them are induced the currents which give a useful effect outside the machine. Now, I am going, to trouble you to go through the mathematical equations, simple though they are, by which the following formulæ are obtained:

$$I = A \sin \frac{2\pi t}{T} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (I.)$$

$$E=\frac{2\pi A}{T}\cos\frac{2\pi t}{T} \quad . \quad . \quad . \quad . \quad . \quad . \quad (II.)$$

$$x=\frac{2\pi A}{T}\frac{\cos 2\pi\frac{t-\tau}{T}}{\sqrt{\left(\frac{2\pi\gamma}{T}\right)^2+R^2}} \quad . \quad . \quad . \quad (III.)$$

$$\mathrm{Tan}\frac{2\pi\tau}{T}=\frac{2\pi\gamma}{RT} \quad . \quad . \quad . \quad . \quad . \quad . \quad (IV.)$$

$$\varphi R\frac{2\pi^2A^2}{T^2}\frac{I}{\left(\frac{2\pi\gamma}{T}\right)^2+R^2} \quad . \quad . \quad . \quad (V.)$$

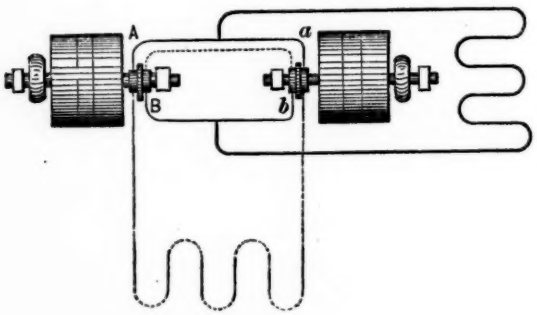
$$R=\frac{2\pi\gamma}{T} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (VI.)$$

T represents the periodic time of the machine; that is, in the case of a Siemens machine having eight magnets on each side of the armature, T represents the time of one-fourth of a revolution. I represents the number of lines of force embraced by the coils of the armature at the time t. I must be a periodic function of t, in the simplest form represented by Equation I. Equation II. gives E the electromotive force acting at time t upon the circuit. Having given the electromotive force acting at any time, it would appear at first sight that we had nothing to do but to divide that electromotive force by the resistance R of the whole circuit, to obtain the current flowing at that time. But if we were to do so we should be landed in error, for the conducting circuit has other properties besides resistance. I pointed out to you that it had a property of momentum represented by its coefficient of self-induction called γ in the formula; and when we are dealing with rapid changes of current, it plays as important a part as the resistance. Formula III. gives the current x, flowing at any time, and you will observe that it shows two things: first the maximum current is less than it would be if there were no self-induction; secondly, it attains its maximum at a later time. This retardation is represented by the letter τ, and its amount is determined by the Formula IV. At a given speed of rotation, the amount of electrical work developed in the machine in any time φ is given by Formula V. It is greatest when $R=\frac{2\pi\gamma}{T}$. From these formulæ we see that the current is diminished either by increasing γ or increasing R; also the moment of reversal of current is not co-incident with the moment of reversal of electromotive force, but occurs later. by an amount depending on the relative magnitudes of γ and R. They show us that although by doubling the velocity of the machine we really double the electromotive force at any time, we do not double the current passing, nor the work done by the machine; but we may see that if we double the velocity of the machine, we may work through double the external resistance, and still obtain the same current. In what precedes, it has been assumed that the copper wires are the only conducting bodies moving in the magnetic field. In many cases the moving wire-coils of these machines have iron cores, the iron being in some cases solid, in others more or less divided. It is found that if such machines are run on open circuit, that is, so that no current circulates in the armatures; the iron becomes hot, very much hotter, than when the circuit of the copper wire is closed. In some cases this phenomenon is so marked that the machine actually takes more to drive it, when the machine is on open circuit, than when it is short-circuited. The explanation is that on open circuit currents are induced in the iron cores, but that when the copper coils are closed, the current in them diminishes by induction the current in the iron. The effect of currents in the iron cores is not alone to waste energy and heat the machine; but for a given intensity of field and speed of revolution, the external current produced is diminished. The cure of the evil is to subdivide the moving iron as much as possible, in directions perpendicular to those in which the current tends to circulate.

There remains one point of great practical interest in connection with alternate-current machines. How will they behave when two or more are coupled together, to aid each other in doing the same work? With galvanic batteries, we know very well how to couple them, either in parallel circuit or in series, so that they shall aid, and not oppose, the effects of each other; but with alternate current machines, independently driven, it is not quite obvious what the result will be, for the polarity of each machine

is constantly changing. Will two machines, coupled together, run independently of each other, or will one control the movement of the other in such wise that they settle down to conspire to produce the same effect, or will it be into mutual opposition? It is obvious that a great deal turns upon the answer to this question, for in the general distribution of electric light, it will be desirable to be able to supply the system of conductors from which the consumers draw by separate machines, which can be thrown in and out at pleasure. Now I know it is a common impression that alternate-current machines cannot be worked together, and that it is almost a necessity

Fig. 6



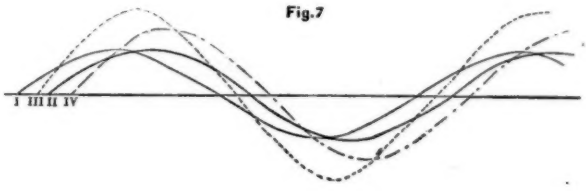
to have one enormous machine to supply all the consumers drawing from one system of conductors. Let us see how the matter stands. Consider two machines independently driven, so as to have approximately the same periodic time and the same electromotive force. If these two machines are to be worked together, they may be connected in one of two ways; they may be in parallel circuit with regard to the external conductor, as shown by the full line in Fig. 6, that is, their currents may be added algebraically and sent to the external circuit, or they may be coupled in series, as shown by the dotted line, that is, the whole current may pass successively through the two machines, and the electromotive force of the two machines may be added, instead of their currents. The latter case is simpler. Let us consider it first. I am going to show that if you couple two such alternate current machines in series, they will so control each other's phase as to nulify each other, and that you will get no effect from them; and, as a corollary from that, I am going to show that if you couple them in parallel circuit, they will work perfectly well together, and the currents they produce will be added; in fact, that you cannot drive alternate-current machines tandem, but that you may drive them as a pair, or, indeed, any number abreast. In diagram, Fig. 7, the horizontal line of abscissæ represents the time advancing from left to right; the full curves represent the electromotive forces of the two machines not supposed to be in the same phase. We want to see whether they will tend to get into the same phase or to get into opposite phases. Now, if the machines are coupled in series, the resultant electromotive force on the circuit will be the sum of the electromotive forces of the two machines. This resultant electromotive force is represented by the broken curve III; by what we have already seen in Formula IV., the phase of the current must lag behind the phase of the electromotive force, as is shown in the diagram by curve IV., thus——.——.——. Now, the work done in any machine is represented by the sum of the products of the currents and of the electromotive forces, and it is clear that as the phase of the current is more near to the phase of the lagging machine II than to that of the leading machine I, the lagging machine must do more work in producing electricity than the leading machine; consequently its velocity will be retarded, and its retardation will go on until the two

machines settle down into exactly opposite phases, when no current will pass; The moral, therefore, is, do not attempt to couple two independently driven alternate-current machines in series. Now for the corollary, AB, Fig. 6, represent the two terminals of an alternate-current machine; *ab* the two terminals of another machine independently driven. A and *a* are connected together, and B and *b*. So regarded, the two machines are in series, and we have just proved that they will exactly oppose each other's effects, that is, when A is positive, *a* will be positive also; when A is negative, *a* is also negative. Now, connecting A and *a* through the comparatively high resistance of the external circuit with B and *b*, the current passing through that circuit will not much disturb, if at all, the relations of the two machines. Hence, when A is positive, *a* will be positive, and when A is negative, *a* will be negative also; precisely the condition required that the two machines may work together to send a current into the external circuit. You may, therefore, with confidence, attempt to run alternate-current machines in parallel circuit for the purpose of producing any external effect. I might easily show that the same applies to a larger number: hence, there is no more difficulty in feeding a system of conductors from a number of alternate-current machines, than there is in feeding it from a number of continuous-current machines. A little care only is required that the machine shall be thrown in when it has attained something like its proper velocity. A further corollary is that alternate currents with alternate current machines as motors may theoretically be used for the transmission of power.*

* Of course in applying these conclusions it is necessary to remember that the machines only *tend* to control each other, and that the control of the motive power may be predominant, and *compel* the two or more machines to run at different speeds.

It is easy to see that, by introducing a commutator revolving with the armature, in an alternate-current machine, and so arranged as to reverse the connection between the armature and the external circuit just at the time when the current would reverse, it is possible to obtain a current always constant in direction; but such a current would be far from constant in intensity, and would certainly not accomplish all the results that are obtained in modern continuous-current machines. This irregularity may, however, be reduced to any extent by multiplying the wires of the armature, giving each its own connection to the outer circuit, and so placing them that the electromotive force attains a maximum successively in the several coils. A practically uniform electric current was first commercially produced with the

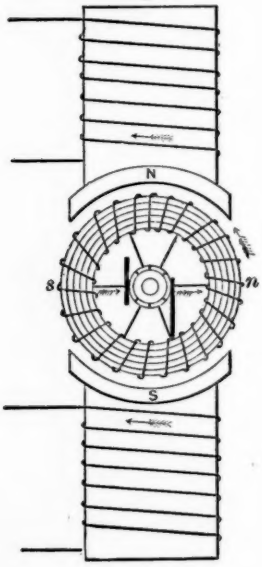
Fig.7



ring armature of Pacinotti, as perfected by Gramme. The Gramme machine is represented diagrammatically in Fig. 8. The armature consists of an anchor ring of iron wire, the strands more or less insulated from each other. Round this anchor ring is wound a continuous endless coil of copper wire; the armature moves in a magnetic field, produced by permanent or electro-magnets with diametrically opposite poles, marked N and S. The lines of magnetic force may be regarded as passing into the ring from N, dividing, passing round the ring and across to S. Thus the coils of wire, both near to N and near to S, are cutting through a very strong magnetic field; consequently there will be an intense inductive action; the inductive action of the coils near N being equal and opposite to the inductive action of the coils near S, it results that there will be strong positive and negative electric potential at the extremities of a diameter perpendicular to the line N S. The electromotive force produced, is made

use of to produce a current external to the machine thus, the endless coil of the armature is divided into any number of sections, in the diagram into six for convenience, usually into sixty or eighty, and the junction of each pair of sections is connected by a wire to a plate of the commutator fixed upon the shaft which carries the armature; collecting brushes make contact with the commutator as shown in the diagram. If the external resistance were enormously high, so that very little current, or none at all passed

Fig. 8



through the armature, the greatest difference of potential between the two brushes would be found when they made contact at points at right angles to the line between the magnets; but when a current passes in the armature, this current causes a disturbing effect upon the magnetic field. Every time the contact of the brushes changes from one contact-plate to the next, the current in a section of the copper coil is reversed, and this reversal has an inductive effect upon all the other coils of the armature. You may take it from me that the net result on any one coil is approximately the same as if that coil alone were moved, and all the other coils were fixed, and there were no reversals of current in them. Now you can easily see that the magnetic effect of the current circulating in the coils of the armature, will be to produce a north pole at *n*, and a south pole at *s*. This will displace the magnetic field in the direction of rotation. If, then, we were to keep the contact points the same as when no current was passing, we should short circuit the sections of the armature at a time when they were cutting through the lines of magnetic force, with a result that there would be vigorous sparks between the collecting brushes and the commutator. To avoid this, the brushes must follow the magnetic field, and also be displaced in the direction of rotation, this displacement being greater as the current in the armature is greater in proportion to the magnetic field. The net effect of this disturbing effect of the current in the armature reacting upon itself is then to displace the neutral points upon the commutator, and consequently somewhat to diminish the effective electromotive force. It is best to adjust the brushes to make contact at a point such that, with the current then passing, flashing is reduced to a minimum, but this point does not necessarily coincide with the point which gives maximum difference of potential. The magnetic field in the Gramme and other continuous dynamo-electric machines, may be produced in several ways. Permanent magnets of steel may be used, as in some of the smaller machines now made, and in all the earlier machines; these are frequently called magneto-machines. Electro-magnets excited by a current from a small dynamo-electric machine, were introduced by Wilde; these may be described shortly as dynamos with separate exciters. The plan of using the whole current from the armature of the machine itself, for exciting the magnets, was proposed almost simultaneously by Siemens, Wheatstone and S. A. Varley. A dynamo, so excited, is now called a series dynamo. Another method is to divide the current from the armature, sending the greater part into the external circuit, and a smaller portion through the electro-magnet, which is then of very much higher resistance; such an arrangement is called a shunt dynamo. A combination of the

two last methods has been recently introduced, for the purpose of maintaining constant potential. The magnet is partly excited by a circuit of high resistance, a shunt to the external circuit, and partly by coils conveying the whole current from the armature. All but the first two arrangements named depend on residual magnetism to initiate the current, and below a certain speed of rotation give no practically useful electromotive force. A dynamo machine is, of course, not a perfect instrument for converting mechanical energy into the energy of electric current. Certain losses inevitably occur. There is, of course, the loss due to friction of bearings, and of the collecting brushes upon the commutator; there is also the loss due to the production of electric currents in the iron of the machine. When these are accounted for, we have the actual electrical effect of the machine in the conducting wire; but all of this is not available for external work. The current has to circulate through the armature, which inevitably has electrical resistance; electrical energy must, therefore, be converted into heat in the armature of the machine. Energy must also be expended in the wire of the electro-magnet which produces the field, for the resistance of this also cannot be reduced beyond a certain limit. The loss by the resistance of the wires of the armature and of the magnets greatly depends on the dimensions of the machine. About this I shall have to say a word or two presently. To know the properties of any machine thoroughly it is not enough to know its efficiency and the amount of work it is capable of doing; we need to know what it will do under all circumstances of varying resistance or varying electromotive force. We must know, under any given conditions, what will be the electromotive force of the armature. Now, this electromotive force depends on the intensity of the magnetic field, and the intensity of the magnetic field depends on the current passing around the electro-magnet and the current in the armature. The current then in the machine is the proper independent variable in terms of which to express the electromotive force. The simplest case is that of the series dynamo, in which the current in the electro-magnet and in the armature is the same, for then we have only one independent variable. The relation between the electromotive force and current is represented by such a curve as is shown in the diagram, Fig. 9. The abscissæ, measured along OX, represent the current, and the ordinates represent the electromotive force in the armiture. When four years ago I first used this curve, for the purpose of expressing the results of my experiments on the Siemens dynamo machine, I pointed out that it was capable of solving almost any problem relating to a particular machine, and that it was also capable of giving good indications of the results of changes in the winding of the magnets, or of the armatures of such machines. Since then M. Marcel Deprez has happily named such curves "characteristic curves." I will give you one or two illustrations of their use. A complete characteristic of a series dynamo

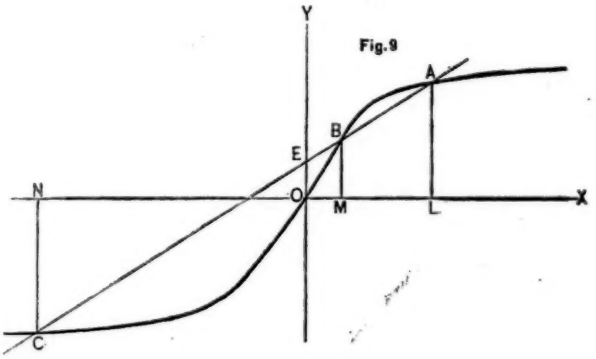


Fig. 9

does not terminate at the origin, but has a negative branch, as shown in the diagram; for it is clear that by reversing the current through the whole machine, the electromotive force is also reversed. Suppose a series dynamo is used for charging an accumulator, and is driven at a given speed, what current will pass through it? The problem is easily solved. Along OY, Fig. 9, set off OE to represent the electromotive force of the accumulator, and through E draw the line CEBA, making an angle with OX, such that its tangent is equal to the resistance of the whole circuit, and cutting the characteristic curve as it in general will do, in three points A, B and C. We have then three answers to the question.

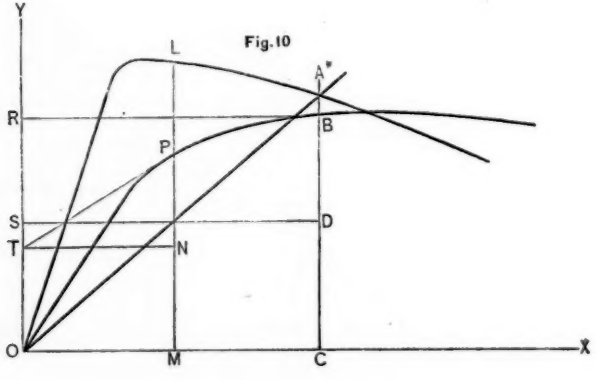


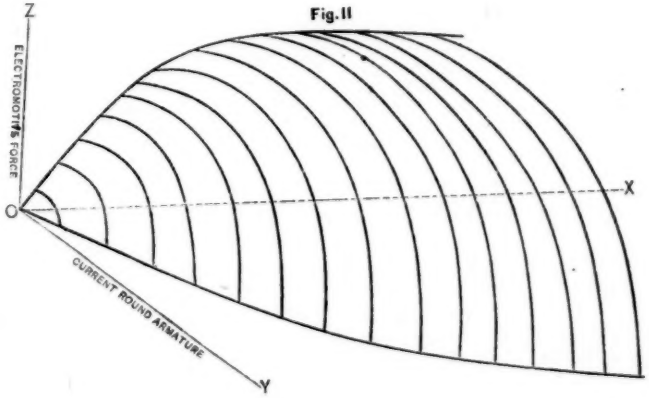
Fig. 10

The current passing through the dynamo will be either OL, OM, or ON the abscissæ of the points where the line cuts the curve. OL represents the current when the dynamo is actually charging the accumulator. OM represents a current which could exist for an instant, but which would be unstable, for the least variation would tend to increase. ON is the current which passes, if the current in the dynamo should get reversed, as it is very apt to do when used for this purpose. The next illustration is rather outside my subject, but shows another method of using the characteristic curve. Many of you have heard of Jacobi's law of maximum effect of transmitting work by dynamo machines. It is this: Supposing that the two dynamo machines were perfect instruments for converting mechanical energy into electrical energy, and that the generating machine were run at constant velocity, whilst the receiving machine had a variable velocity, the greatest amount of work would be developed in the receiving machine when its electromotive force was one-half that of the generating machine, then the efficiency would be one-half, and the electrical work done by the generating machine would be just one-half of what it would be if the receiving machine were forcibly held at rest. Now this law is strictly true if, and only if, the electromotive force of the generating machine is independent of the current passing through its armature. What I am now going to do is to give you a construction for determining the maximum work which can be transmitted when the electromotive force of the generating machine depends on the current passing through the armature, as, indeed, it nearly always does, referring to Fig. 10. OPB is the characteristic curve of the generating machine; construct a derived curve thus, at successive points P of the characteristic curve, draw tangents PT, draw TN parallel to OX, cutting PM in N, produce MP to L, making LP equal PN; the point L gives the derived curve, which I want. Now, to find the maximum work which can be transmitted, draw OA at such angle with OX that its tangent is equal to twice the resistance of the whole circuit, cutting the derived curve in A. Draw the ordinate AC, cutting the characteristic curve in B; bisect AC at D. The work expended upon the generating machine would be represented

by the parallelogram OCBR, the work wasted in resistance by OCDS, and the work developed in the receiving machine by the parallelogram SDBR.

When the dynamo-machine is not a series dynamo, but the currents in the armature and in the electro-magnet, though possibly dependent upon each other are not necessarily equal, the problem is not quite so simple. We have, then, two variables, the current in the electro-magnet and the current in the armature; and the proper representation of the properties of the machine will be by a characteristic surface such as that illustrated by this model, Fig. 11. Of the

Fig. 11

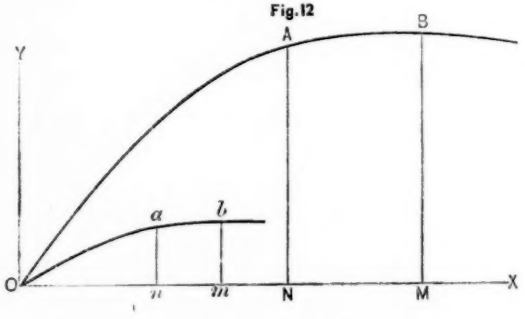


three co-ordinate axes, OX represents the current in the magnet; OY represents the current in the armature not necessarily to the same scale, and OZ the electromotive force. By the aid of such a surface as this one may deal with any problem relating to a dynamo-machine, no matter how its electro-magnets and its armature are connected together. Let us apply the model to find the characteristic of a series dynamo. Take a plane through OZ, the axis of electromotive force, and making such an angle with the plane OX, OZ, that its tangent is equal to current unity on axis OY, divided by current unity on axis OX. This plane cuts the surface in a curve. The projection of this curve on the plane OX, OZ is the characteristic curve of the series dynamo. This model only shows an eighth part of the complete surface. If any of you should interest yourselves about the other seven parts, which are not without interest, remember that it is assumed that the brushes always make contact with the commutator at the point of no flashing, if there is one. Of course in actual practice one would not use the model of the surface, but the projections of its sections. While I am speaking of characteristic curves there is one point I will just take this opportunity of mentioning. Three years ago, Mr. Shoolbred exhibited the characteristic curve of a Gramme machine, in which, after the current attained to a certain amount, the electromotive force began to fall. I then said that I thought there must be some mistake in the experiment. However, subsequent experiments have verified the fact; and when one considers it, it is not very difficult to see the explanation. It lies in this: after the current attains to a certain amount the iron in the machines becomes magnetically nearly saturated, and consequently an increase in the current does not produce a corresponding increase in the magnetic field. The reaction, however, between the different sections of the wire on the armature goes on increasing indefinitely, and its effect is to diminish the electromotive force.

A little while ago I said that the dimensions of the machine had a good deal to do with its efficiency. Let us see how the properties of a machine depend upon its dimensions. Suppose two machines alike in every particular excepting that the one has all its linear dimensions

double that of the other; obviously enough all the surfaces in the larger would be four times the corresponding surfaces in the smaller, and the weights and volumes of the larger would be eight times the corresponding weights in the smaller machines. The electrical resistances in the larger machine would be one-half of the smaller. The current required to produce a given intensity of magnetic field would be twice as great in the larger machine as in the smaller. In the diagram, Fig. 12, are shown the comparative characteristic curves of the two machines, when driven at the same speed. You will observe that the two curves are one the projection of the other, having corresponding points with abscissæ in the ratio of one to two, and the ordinates in the ratio of one to four. Now at first sight it would seem as though, since the wire on the magnet and armature of the larger machine has four times the section of that of the smaller, that four times the current could be carried, that consequently the intensity of the magnetic field would be twice as great, and its area would be four times as great, and hence the electromotive force eight times as great; and since the current in the armature also is supposed to be four times as great, that the work done by the larger machine would be thirty-two times as much as that which would be done by the smaller. Practically, however, no such result can possibly be attained, for a whole series of reasons. First of all, the iron of the magnets becomes saturated, and consequently instead of getting eight times the electromotive force, we should only get four times the electromotive force. Secondly, the current which we can carry in the armature is limited by the rate at which we can get rid of the heat generated in the armature. This we may consider as proportional to its surface, consequently we must only waste four times as much energy in the armature of the larger machine as in the smaller one, instead of eight times, as would be the case if we carried the current in proportion to the section of the wire. Again, the larger machine cannot run at so great an angular velocity as the smaller one. And lastly, since in the larger machine the current in the armature is greater in proportion to the saturated magnetic field than it is in the small one, the displacement of the point of contact of the brushes with the commutator will be greater. However, to cut the matter, about which one might say a great deal, short, one may say that the capacity of similar dynamo-machines is pretty much proportionate to their weight, that is, to the cube of their linear dimensions; that the work wasted in producing the magnetic field will be directly as the linear dimensions; and that the work wasted in heating the wires of the armature will be as the square of the linear dimensions. Now let us see how this would practically apply. Suppose we had a small machine capable of producing an electric current of 4 HP., that of this 4 HP. 1 was wasted in heating the wires of the armature, and 1 in heating the wires of the magnet, 2 would be usefully applied outside. Now, if we doubled the linear dimensions we should have a capacity of 32 HP., of which 2 only, if suitably applied, would be required to produce the magnetic field and 4 would be wasted in heating the wires of the

Fig. 12



armature, leaving 26 HP. available for useful work outside the machine—a very different economy from that of the smaller machines. But if we again doubled the linear dimensions of our machine, we should by no means obtain a similar increase of effect. A consideration of the properties of similar machines has another very important practical use. As you all know, Mr. Froude was able to control the design of ironclad ships by experiments upon models made in paraffin wax. Now, it is a very much easier thing to predict what the performance of a large dynamo-machine will be, from laboratory experiments made upon a model of a very small fraction of its dimensions. As a proof of the practical utility of such methods, I may say that by laboratory experiments I have succeeded in increasing the capacity of the Edison machines without increasing their cost, and with a small increase of their percentage of efficiency, remarkably high as that efficiency already was.

I might occupy your time with considerations as to the proper proportion of conductors, and explain Sir W. Thomson's law, that the most economical size of a copper conductor is such that the annual charge for interest and depreciation of the copper of which it is made, shall be equal to the cost of producing the power which is wasted by its resistance. But the remaining time will, perhaps, be best spent in considering the production of light from the energy of electric currents. You all know that this is done commercially in two ways, by the electric arc, and by the incandescent lamp; as the arc lamp preceded the incandescent lamp historically, we will examine one or two points connected with it first.

I have here all that is necessary to illustrate the electric arc, viz., two rods of carbon supported in line with each other, and so mounted that they can be approached or withdrawn. Each carbon is connected with one of the poles of the Edison dynamo machine, which is supplying electricity to the incandescent lamps which illuminate the whole of this building. A resistance is interposed in the circuit of the lamp, because the electromotive force of the machine is much in excess of what the lamp requires. I now approach the carbons, bring them into contact, and again separate them slightly; you observe that the break does not stop the current which forces its way across the space. I increase the distance between the carbons, and you observe the electric arc between their extremities; at last it breaks, having attained a length of about one inch. Now the current has hard work to cross this air-space between the carbons, and the energy there developed is converted into heat, which raises the temperature of the ends of the carbon beyond any other terrestrial temperature. There are several points of interest I wish to notice in the electric arc. Both carbons burn away in the air, but there is also a transference of carbon from the positive to the negative carbon; therefore, although both waste away, the positive carbon wastes about twice as fast as the negative. With a continuous current, such as we are using now, the negative carbon becomes pointed, whilst the positive carbon forms a crater or hollow; it is this crater which becomes most intensely hot and radiates most of the light, hence the light is not by any means uniformly distributed in all directions, but is mainly thrown forward from the crater in the positive carbon. This peculiarity is of great advantage for some purposes, such, for example, as military or naval search lights, but it necessitates, in describing the illuminating power of an arc light, some statement of the direction in which the measurement was made. On account of its very high temperature the arc light sends forth a very large amount of visible radiation, and is therefore very economical of electrical energy. For the same reason its light contains a very large proportion of rays of high refrangibility, blue and ultra-violet. I have measured the red light of an electric arc against the red of a candle, and have found it to be 4,700 times as great, and I have measured the blue of the same arc light against the blue of the same candle, and found it to 11,380 times as great. The properties of an electric arc are not those of an ordinary conductor. Ohm's law does not apply. The electromotive force and the current do not by any means bear to each other a constant ratio. Strictly speaking, an electric arc cannot be said to have an electric resistance measureable in ohms. We will now examine the

electrical properties of the arc experimentally. In the circuit with the lamp is a Thomson graded current galvanometer for measuring the current passing in amperes; connected to the two carbons is a Thomson graded potential galvanometer, for measuring the difference of potential between them in volts. We have the means of varying the current by varying the resistance, which I have already told you is introduced into the circuit. We will first put in circuit the whole resistance available, and will adjust the carbons so that the distance between them is, so near as I can judge, $\frac{1}{8}$ inch. We will afterwards increase the current, and repeat the readings. The results are given in the following table:

Current galvanometer.	Potential galvanometer.	Ampères	Volts.	Watts.	HP.
6.2	12.0	9.9	35	346	0.46
9.3	12.0	14.9	35	521	0.70
11 5	11.8	18.4	34	626	0.84

If the electrical properties of the arc were the same as those of a continuous conductor, the volts would be in proportion to the amperes, if correction were made for change of temperature; you observe that instead of that the potential is nearly the same in the two cases. We may say, with some approach to accuracy, that with a given length of arc the arc opposes to the current an electromotive force nearly constant, almost independent of the current. This was first pointed out by Edlund. If you will speak of the resistance of the electric arc, you may say that the resistance varies inversely as the current. Take the last experiment: by burning 4 cubic feet of gas per hour we should produce heat-energy at about the same rate. I leave any of you to judge of the comparative illuminating effects. It is not my purpose to describe the mechanisms which have been invented for controlling the feeding of the carbons as they waste away. Several lamps lent by Messrs. Siemens Brothers—to whom I am indebted for the lamp and resistance I have just been using — lie upon the table for inspection. An electric arc can also be produced by an alternate current. Its theory may be treated mathematically, and is very interesting, but time will not allow us to go into it. I will merely point out this: there is some theoretical reason to suppose that an alternate-current arc is in some measure less efficient than one produced by a continuous current. The efficiency of a source of light is greater, as the mean temperature of the radiating surface is greater. The maximum temperature in an arc is limited probably by the temperature of volatilization of carbon; in an alternate-current arc the current is not constant, therefore the mean temperature is less than the maximum temperature; in a continuous-current arc, the current being constant, the mean and maximum temperatures are equal, therefore in a continuous-current arc the mean temperature is likely to be somewhat higher than in an alternate-current arc.

We will now pass to the simpler incandescent light. When a current of electricity passes through a continuous conductor, it encounters resistance, and heat is generated, as was shown by Joule, at a rate represented by the resistance multiplied by the square of the current. If the current is sufficiently great the heat will be generated at such a rate that the conductor rises in temperature so far that it becomes incandescent and radiates light. Attempts have been made to use platinum and platinum-iridium as the incandescent conductor, but these bodies are too expensive for general use, and besides, refractory though they are, they are not refractory enough to stand the high temperature required for economical incandescent lighting. Commercial success was not realized until very thin and very uniform threads or filaments of carbon were produced and enclosed in reservoirs of glass, from which the air was exhausted to the utmost possible limit. Such are the lamps made by Mr. Edison with which this building is lighted to-night. Let us examine the electrical properties of such a lamp. Here is a lamp intended to carry the same current as those overhead, but of half the resistance, selected because it leaves us a margin of electromotive force wherewith to vary our experiment. Into its circuit I am able to introduce a resistance for checking the current, composed of other incandescent lamps for convenience, but which I shall cover over that they may

not distract your attention. As before, we have two galvanometers, one to measure the current passing through the lamp, the other the difference of potential at its terminals. First of all we will introduce a considerable resistance; you observe that, although the lamp gives some light, it is feeble and red, indicating a low temperature. We take our galvanometer readings. We now diminish the resistance, the lamp is now a little short of its standard intensity; with this current it would last 1000 hours without giving way. We again read the galvanometers. The resistance is diminished still further. You observe a great increase of brightness, and the light is much whiter than before. With this current the lamp would not last very long. The results are given in the following table:

Current galvanometer.	Potential galvanometer.	Ampères.	Volts.	Watts	Resistance ohms.
5.2	12.8	0.38	37	14	97
6.0	14.3	0.44	41	18	93
11.5	23.4	0 84	68	57	81

There are three things I want you to notice in these experiments: first, the light is whiter as the current increases; second, the quantity of light increases very much faster than the power expended increases; and thirdly, the resistance of the carbon filament diminishes as its temperature increases, which is just the opposite of what we should find with a metallic conducter. This resistance is given in ohms in the last column. To the second point, which has been very clearly put by Dr. Siemens in his British Association address, I shall return in a minute or two.

The building is this evening lighted by about 200 lamps, each giving sixteen candles' light, when 75 watts of power are developed in the lamp. To produce the same sixteen candles' light in ordinary flat-flame gas-burners, would require between seven and eight cubic feet of gas per hour, contributing heat to the atmosphere at the rate of 3,400,000 foot-pounds per hour, equivalent to 1250 watts, that is to say, equivalent gas lighting would heat the air nearly seventeen times as much as the incandescent lamps.

Look at it another way. Practically, about eight of these lamps take one indicated horse-power in the engine to supply them. If the steam engine were replaced by a large gas engine this 1 HP. would be supplied by 25 cubic feet of gas per hour, or by rather less; therefore by burning gas in a gas engine driving a dynamo, and using the electricity in the ordinary way in incandescent lamps, we can obtain more than 5 candles per cubic foot of gas, a result you would be puzzled to obtain in 16-candle gas burners. With arc lights instead of incandescent lamps many times as much light could be obtained.

At the present time, lighting by electricity in London must cost something more than lighting by gas. Let us see what are the prospects of reduction of this cost. Beginning with the engine and boiler, the electrician has no right to look forward to any marked and exceptional advance in their economy. Next comes the dynamo. the best of these are so good, converting 80 per cent. of the work done in driving the machine into electrical work outside the machine, that there is little room for economy in the conversion of mechanical into electrical energy; but the prime cost of the dynamo-machine is sure to be greatly reduced. Our hope of greatly increased economy must be mainly based upon probable improvements in the incandescent lamp, and to this the greatest attention ought to be directed. You have seen that a great economy of power can be obtained by working the lamps at high-pressure, but then they soon break down. In ordinary practice, from 140 to 200 candles are obtained from a horse power developed in the lamps, but for a short time I have seen over 1000 candles per horse-power from incandescent lamps. The problem, then, is so to improve the lamp in details, that it will last a reasonable time when pressed to that degree of efficiency. There is no theoretical bar to such improvements, and it must be remembered that incandescent lamps have only been articles of commerce for about three years, and already much has been done. If such an improvement were realized, it would mean that you would get five times as much light for a sovereign, as you can now. As things now stand, so soon as those who supply elec-

tricity have reasonable facilities for reaching their customers, electric lighting will succeed commercially where other considerations than cost have weight. We are sure of some considerable improvement in the lamps, and there is a probability that these improvements may go so far as to reduce the cost to one-fifth of what it now is. I leave you to judge whether or not it is probable, nay, almost certain, that lighting by electricity is the lighting of the future.

WATER SUPPLY OF SAN FRANCISCO FROM LAKE MERCED.

By P. J. FLYNN, Civil Engineer.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

THE following is a brief report submitted on the water supply of San Francisco, California, from Lake Merced. Lake Merced is situated about six miles in a south-westerly direction from a central point the new City Hall of San Francisco, and it is within about a quarter of a mile of the Pacific coast. Part of the lake is within the municipal boundary of San Francisco.

Omitting all consideration of cost, the points requiring investigation are:

1st. The *quantity* of water available from the lake to supply the city.

2d. The *quality* of the water for domestic purposes.

In order to make a satisfactory report the flow from the outlet to the lake should be gauged daily for several years, *including a dry season*, the rainfall noted for the same time and the water analyzed frequently—about once a week—for the space of one year. I fail to find that this has been done in the case of Lake Merced. I, however, avail myself of the information contained in the reports of the engineers heretofore employed to report on the water supply of the city.

As being of little use, for the purpose of this report, I omit a detailed description of the lake and its surrounding watershed.

The area of the lake is given as 331 acres, and the area of its watershed seven and one-half square miles. The water supply of the lake is derived from the rainfall. The watershed, composed chiefly of sand, acts as an immense storage reservoir and the uniformity of flow from it to the lake is such that works of an inexpensive nature will prevent any loss by waste from the lake should it be used as a service reservoir. According to the gaugings then made, I find that the watershed stored in 1874 a supply sufficient to fill a reservoir one mile long, 1,041 feet wide and 50 feet deep.

The only supply that there is any proof of, is rainfall, and this alone will be estimated for in this report. Engineers differ in opinion as to whether there is an artesian supply in addition to the rainfall, but, as *proof is wanting* that such a supply exists, the safest plan is to make no allowance for it. If such a supply exists it must be small, as Mr. Schussler at one time found the flow from the lake to be only 1,500,000 gallons per day.

The gaugings taken at the outlet show considerable variation in the flow from the lake: Mr. Scowden gauged 5,680,434 gallons per day; Mr. Allardt, 5,500,000 gallons; Messrs. Schussler and Elliott, 2,500,000 gallons, and 1,750,000 gallons; Colonel Von Schmidt, 10,000,000 gallons; Mr. Schussler, 1,500,000 gallons, and 55,000,000 gallons.

Mr. Scowden gives the area of the watershed as 7½ square miles, and he estimates the *average* of 25 years rainfall as 23.9 inches per annum, the same as San Francisco. The total average daily rainfall will therefore be equal to 8,534,630 gallons per day. In no case, however, does all the rain that falls on a watershed flow off. A certain portion is lost in evaporation and infiltration. Even a steep surface of granite does not shed all the rainfall. After gauging the outflow of the lake, Mr. Scowden estimated that 66 per cent. of a total rainfall of 23.9 inches per annum could be utilized. The loss, therefore, was 34 per cent., equal to 8.12 inches rainfall. This I consider a fair estimate, and I adopt it. A yearly rainfall of 23.9 inches gives an

average daily supply of 8,534,630 gallons, and 66 per cent. of this amounts to 5,632,855 gallons per day available for a water supply.

Mr. Scowden, in his estimates, adopted a supply of 100 gallons of water per individual per day, and Colonel Mendell adopted 50 gallons as a *minimum*. No doubt 30 gallons is an ample supply for all purposes if the water is used carefully, but the experience of almost all cities in Europe and America, having a constant supply of water, is that more is allowed run to waste than is actually used, and no means have yet been found to effectually check this waste. New York was sometime since expending at the rate of over 100 gallons per individual per day. For this report I adopt Colonel Mendell's *minimum* allowance of 50 gallons per day. At this rate 5,632,855 gallons per day will suffice for a population of 112,657 only, being probably not more than one-third of the population of the city at the present time.

As the strength of a bridge is measured by its weakest part, so is the utility of a watershed measured by its driest season, except where there is a storage reservoir of sufficient capacity to retain enough of water to compensate for loss during a dry season.

A small rainfall does not, especially in sandy ground, give a supply proportionate to a large rainfall. For instance, a rainfall of seven inches will not give a supply one-fourth of that given by a rainfall of 28 inches. The reason of this is that the quantity lost through evaporation and infiltration may, practically, be taken as *constant*. I will give a familiar illustration. Place a large sponge in an empty vessel and pour a measured quantity of water over it. After it is saturated take it out and press, with your hands, as much of the water out of it and into the vessel as you can do. The vessel has lost say, one-half a pint of water. This loss is a *constant quantity*, for, if you increased the quantity of water poured over the sponge, the quantity retained by it will be the same. Something similar is the case with the water sheds. A *constant quantity* of water is lost, irrespective of the rainfall. From what has been already said it is evident that the constant yearly loss on the Lake Merced watershed is 34 per cent. of 23.9 inches of rainfall, that is, 8.12 inches of rainfall, the available supply being 66 per cent.

Colonel Mendell, in his report, gives a table of the rainfall of San Francisco, as recorded by Mr. Thomas Tennant, from July to July of the years 1849 to 1877 inclusive. In this statement the rainfall is given for 1850–51 equal to 7.4 inches, 1851–52 equal to 18.44 inches, 1862–63 equal to 13.62 inches, 1863–64 equal to 10.08 inches, 1869–70 equal to 19.31 inches, 1870–71 equal to 14.10 inches. We have here on an average, one dry year in about every three. Then again we have four dry years in the space of nine years, and on three occasions two consecutive dry years.

In the following table it will be seen that the water that can be utilized in dry years is sufficient to supply only a small percentage of the present population of the city:

Years.	Rainfall in inches	Available rainfall*	Gallons per day.	Population at 50 gallons per day.
1850–51.	7.40	0.72	—	—
1851–52.	18.44	10.32	3,684,983	73,699
1862–63.	13 62	5.50	1,963,896	39,277
1863–64.	10.08	1.96	699,861	13,997
1869–70.	19.31	11.19	3,995,635	79,912
1870–71.	14.10	5.98	2,135,290	42,706

It is very likely that there was little, if any, flow from the lake in 1850–51, especially during the dry months, as the supply was only 7.4 inches and the *constant loss* 8.12 inches. Then comes another dry year with a supply for a population of 39,277. The above table shows that, taken in the most favorable light, the supply for six out of twenty years falls far short of that required for one-third of the present population. What has happened before in the occurrence of dry years, at intervals, is almost certain to happen again. The only safe course, therefore, is to estimate on the basis of the least known supply. The least known supply of Lake Merced would cause a *complete water famine*. A small watershed like that of Lake Merced is

* The total rainfall less 8 12 inches, the constant loss.

more liable to great variation in its rainfall than a large one.

The following has been published in favor of Lake Merced supply.

"It may be objected that 8,000,000 gallons per day would not be sufficient to supply San Francisco. Admit that fact, and what does it prove? Does it prove that we should reject that much cheap water because we cannot have it all cheap? The city of London is said to be supplied by some eight different companies." The great disadvantages of having so many companies have been long felt by the London public, and a great deal has been written on the subject. Several eminent engineers have reported at length on a single supply to replace all the other supplies. The question took such hold of the public attention some years since, that the British Government appointed a Royal Commission to investigate the subject of water supply. This Commission took evidence for nearly two years, from February, 1867, to December, 1868, the bulk of the evidence, which fills a large volume, being plans and suggestions from engineers and other scientific men, for a single supply for London. Water supply is at the present time receiving a great deal of attention, and it is probable that at no distant day a single supply will be introduced to supply all London.

A growing city like San Francisco demands such a supply as will meet all its present and future requirements, until the city reaches a population of at least a million. The supply should be equal to all the wants of the city, including domestic purposes, manufactories, street sprinkling, irrigation of gardens, and sewer flushing.

The next point for consideration is the *quality* of the water. What is required is a supply that not only is pure now, but that also, so far as is known, is likely to remain pure so long as that supply is required.

Colonel Mendell estimates, from the former growth of the city, that it will have a population of 500,000 in 1887, and 800,000 in 1897. As part of the lake is within the municipal boundary of San Francisco, it is reasonable to believe that, long before the population reaches the latter number, a large portion of the watershed of Lake Merced will be built over and occupied by several thousand inhabitants.

Before sewers are constructed cesspools will be one of the means adopted to provide for the disposal of the sewage. This sewage will pollute the subsoil. At the same time the surface of unpaved streets and thoroughfares will be formed of a mass of accumulated filth. Even after sewers are constructed the leakage from them into the sandy subsoil will contaminate the water supply of the lake. The rain, before reaching the lake, will have to pass through the surface deposit and subsoil. It will, very likely, be said that this water will be filtered by passing through the sand before reaching the lake. In the year 1875 a commission appointed by the British Government, to report on the pollution of rivers, stated with reference to water polluted with sewage:

"The only safe course is to avoid altogether the use, for domestic purposes, of water which has been polluted with excrementitious matters." This is very explicit. The large cemetery which it is proposed to locate within the watershed will be another cause of pollution to the waters of the lake.

As streets and sewers spread over the watershed, the *supply of water* will steadily *decrease*, whilst, at the same time, *sewage pollution* will steadily *increase*. All the rain falling on the inhabited district will not be intercepted from the lake, but the quantity that reaches the lake from it will be polluted.

During heavy rains the surface flow from the inhabited district will be strongly impregnated with sewage, and this can be prevented from reaching the lake only by the construction of costly intercepting sewers or open channels. This will be, however, at the expense of the supply of water to the lake. It will thus be seen that as the watershed is built over the supply of water to the lake will steadily decrease, and pollution increase, and eventually the *watershed will become a sewage shed*, the supply that it will shed to the lake being, in fact, *diluted sewage*. The poisoning of the water of the lake will be cumulative. It may be objected to this, that as there will be a constant flow to and from the

lake, keeping its water always free from stagnation, therefore the sewage can do no material damage. On this subject, and with reference to flowing rivers polluted with sewage, the Rivers Pollution Commissioners above mentioned state:

"All the processes that have yet been offered for the purpose of cleansing such polluted water have proved ineffective to produce a resulting effluent fit for drinking and domestic purposes after such a contamination with sewage or other animal refuse.

Contrast Lake Merced with a flowing river under the above circumstances, and the verdict will not be in its favor. Chicago constructed a tunnel *two miles long under the bed of Lake Michigan* in order to place the inlet for its water supply beyond the reach of the contaminated waters along its margin.

Even if it is admitted that the waters of Lake Merced will remain pure, still the quantity of water, for all useful purposes of water supply to a large city, will eventually fail. In addition to the quantity of water carried off by the sewers a further quantity will be taken up by wells, which will be sunk as the district becomes inhabited, and the supply will gradually diminish, until the quantity of water reaching the lake will scarcely suffice to compensate for the infiltration from the lake and evaporation from its surface. No flow will ther. take place from the lake, and its water will be almost stagnant.

Long before the land around Lake Merced is fully built over, the most stringent measures will have to be adopted, and costly intercepting sewers constructed, to prevent this becoming a hot-bed of disease. I do not mean from the use of its water, but from the poisonous exhalations and deadly malaria that are likely to arise from it in hot weather, if the surface storm flow of the streets be not prevented from reaching it and converting it into a sewage reservoir.

Lake Merced, as a source of water supply for the city, has in its favor, its location near the city, and consequently, causing a minimum of expense, in cost of works, pumping and repairs.

Its disadvantages are:

1. That its supply is totally inadequate to the present and future wants of the city.

2. That its water, admitting its purity at the present time, can be kept pure only by the prevention of the extension of the city over its watershed.

THE EFFECT ON ARCHITECTURE OF LIABILITY TO EARTHQUAKES.

From "The Builder."

THE fatal and destructive earthquake in the Island of Ischia, of the magnitude of which each day brings further accounts, recalls, to those who had any experience of its effects, the yet more fatal catastrophe which desolated Calabria early in 1858. We are writing with personal experience only of the fringe of this terrible earthquake, which is said to have cost the lives of 30,000 Italians. Potenza, in the province of Basilicata, which is called the home and cradle of earthquakes, was the central point of disturbance in 1858, and the speed at which the shock traveled was estimated, after careful inquiry, at 775 ft. per second, or nearly half the velocity of sound in the air. At Naples itself but little damage was done. But this was due rather to the solid excellence of the work of the Italian architects than to the feeble nature of the shocks, which continued through an entire night. The first was the most severe of these shocks, being followed almost immediately by the *replica*, or return shock, which is always the most dreaded part of the disturbance. Some idea of the intensity of the action at Naples may be formed from the following brief account. The writer was seated in a large saloon in a palace in Naples, which had formerly been that of the Spanish viceroys, and which is close on the shore of the bay. About nine o'clock in the evening, when some of the citizens were at the opera, the first shock came, without any premonitory symptoms. Its violence was, to some extent,

to be measured by the amplitude of the oscillations of a large chandelier, depending from the ceiling, which swung through an arc of more than 99°. And as to duration, there was enough time to rise, to cross the room, and to go out on to a terrace overlooking the bay, while the noise and vibration continued. On arriving at the edge of the terrace, the observer had to cling to the railing for support, as the whole building rocked like a ship at sea; and the walls of the lowest story of the palace in question are 17 ft. thick.

The houses of Naples were emptied by the shock, the entire population, in every condition of dress and undress, pouring out into the streets, where they remained for the remainder of the night, the nobles and wealthier inhabitants sleeping in their carriages. And yet it was said that only one stone was shaken from its place in Naples. There was one point to which the natives flocked with interest on the next morning to see how far art had withstood the fierce anger of nature. It was the gate of a *porte cochere*—that of the Palais of Justice, if we rightly remember—where a wide and delicate hood of masonry stretched over the gateway almost like a piece of textile work. The stone hood was uninjured.

In these regions, built on tufa, and thus in almost organic connection with the sources of volcanic energy, the architect has to gird up his loins in order to take his part in a very serious struggle. A house in Naples is estimated to last for 100 years, undergoing in that time two pretty complete renovations. Of the solidity of the work an idea can be formed from the thickness of those 17 ft. walls of which we have spoken. They, indeed, are exceptional, but not so exceptional as might be imagined. Walls of a thickness of 3 ft. and 4 ft. in any building of considerable size, of fifty or sixty years old, are rarely undisfigured by seams which tell of past earthquakes. The Royal Palace at Caserta, a masterpiece of Vanvitelli, and built with little regard to expense, is disfigured by not a few vertical seams, which bear witness to the violence of the shocks which, at different dates, rent but could not overthrow the noble structure.

We are not aware that any such local differences in the effects of the shock were witnessed in Naples in 1858, as was the case in Lisbon in 1755, owing to the different conductive powers of different geological formations. But for the whole circle of the bay, which measures some twelve miles straight across from Naples to Sorrento, the movement of that night elevated the ground by about 8 in., a level which it maintained at all events for five or six years thereafter.

It is quite easy to understand how in a locality subject to such disturbances, the normal proportions of houses are of quite another strength from those with which the English architect is familiar. And there are two or three peculiarities to which it was well to direct attention. The responsibility of the architect, or of the builder is of a much more serious nature in Naples than it is with us. It extends, by common law, so as to cover maintenance for a definite time; and thus the builder, for his own sake, builds strongly. Thus, brickwork, as we have it, is unknown to Naples. Most of the building are of stone or tufa, and when *mattone*, or brick, is used, it is in the form of the flat Roman bricks, or rather tiles, of which we have some instances in the remains of Roman work in this country, and of which the strength and durability are extraordinary. *Mattone* is more costly than the tufa generally used for internal work in Naples, and it is also considered more durable. In the third place, there is no doubt that the mortar used by the Italian builder is far better than any commonly used in England. And this is the more worthy of attention, because, as has been before noticed in the *Builder*, the principle of making mortar is contrary to that generally adopted by English engineers and architects. Probably no one in our day has studied the question of masonry more carefully than did I. K. Brunel. His designs for the bridges and other works on the Great Western, the South Wales, and other railways to which he was engineer, were exceptionally light and bold; his aim being to employ a small bulk of the very finest work, in preference to a larger bulk of ordinary work. To this end his specifications were drawn with a care that was never wearied; his great energies continually bringing out fresh editions of his normal masonry specification. The mortar was prescribed to be made with fresh slaked lime, mixed while yet hot,

and any mortar not used in the course of the day in which it was mixed was to be removed from the work by the contractor. The lime was also the subject of very careful provisions.

In Southern Italy, on the contray, the lime is slaked a year, or by preference two years, before it is made into mortar. The first thing done on commencing a building is to dig a pit into which as much lime as is thought likely to be required for the work is cast, and covered with water. It is so kept, as far as possible, under water during the whole progress of the work—being dug out as a damp paste for mixing with sand prior to use. As to the excellence of the result there can be no manner of doubt—any more than as to the apt and ready skill of the Italian masons, who have all the facilities at their command that we usually regard as in the province of the carpenter. The centers of arches, for example, instead of being built of wood, and lagged, are roughly and rapidly built of stone, and smoothed over with earth or clay, to receive the permanent arch stones. We have seen in a week or two after one of those local earthquakes at the foot of Mount Vesuvius—which did much more damage in that part of Campania than did the wasted energy of the Potenza earthquake of 1858—the cracks in the houses soldered up, the broken lintels replaced, and a large building that looked a hopeless ruin restored to a habitable condition in a few weeks, by the industry of the Italian masons. And of the confidence which this craftsman puts in his work, the excellence of the mortar no doubt is not the least determining condition.

Professor Palmieri, the seismologist, or earthquake doctor, has been writing to give his opinion that the catastrophe at Ischia was due to subterranean subsidence rather than to earthquake proper. And Mr. Mallet, M. Ins. C.E., who made a special study of the phenomena of the earthquake of 1858, of which we have spoken, maintains that all earthquakes are the effect of such subsidence. We cannot ourselves, having witnessed repeated earthquakes of more or less activity, subscribe to any doctrine that attributes these alarming phenomena to so simple a physical cause—a cause, moreover, which is not only hypothetical, but not very easy to explain on its own account. That there is something of the nature of the electric shock in the earthquake, we think most physicists who have any experience of the sensation caused will hold. We desire to speak with all modesty, and that the more so from our only very recent acquaintance with the fact that electricity, as a source either of light or of motion, is now known to be convertible into heat or other forms of motion. Thus, that an internal shock, such as that produced by the fall of the roof of a great cavern, might arrive at the surface of the earth as an electric disturbance, is quite in harmony with what we know of what is now called dynamo-motor power. But then our experience of mines, tunnels, salt works and the like, is rather opposed to the notion of any such internal cavities forming themselves under the action of water. It is possible that the different conductivity of different geological strata, of which we have witnessed with our own eyes the very evident proof that is to this day presented in the streets of Lisbon, may, if carefully studied, throw some light on this question. Subsidence is not a new phenomenon; and in cases like those of the thick coal-seam of Staffordshire, and the salt-veins and brine-pumpings of Cheshire, a much greater amount of subterranean erosion is at work than we can in any way attribute to the percolation of water in any part of the globe. But though houses are ruined, districts made bare and waste, and lakes formed by subsidence in Staffordshire and in Cheshire, we have no earthquakes there. On the other hand, to witness, after a series of shocks, whether occurring in a few minutes or extending for some days, a displacement such as that of the Bay of Naples, or the effects of the more violent local shocks which rent nearly every house at Torre del Greco, Torre Annunziata, and Resina, and that threw out a spring of hot water that ran for three weeks, betokens, we imagine, some far more violent energy than the subsidence of the roof of an unknown cavern. The terror that the earthquake causes, not in mankind alone, but in the whole animal kingdom, is a special feature of these terrific visitations. The idea that this terror is caused by any process of reasoning is one not to be entertained by any who have experienced it. That

there is something akin to electricity in the shock of the earthquake is, we think, proved, among other things, by the nature of the panic instinctively caused in man and beast by even the lightest shock. In the case of an earthquake slightly felt in Wiltshire, some ten years ago, our own attention was roused by the violent terrors evinced by a pair of Australian grass parakeets. We had not noticed the shock, but we did note the time thus fixed; and on the following day the newspapers gave accounts of a shock of earthquake felt in that part of England at the precise moment indicated by the terror of the birds.

WATER POWER OF THE SOUTHERN ATLANTIC SLOPE.

By MR. GEORGE F. SWAIN.

Proceedings of the Society of Arts.

THE 282d meeting of the Society of Arts was held on Thursday, March 23d, at 7.30 P.M., President Francis A. Walker in the chair. After the transaction of some matters of business, the President introduced Mr. Geo. F. Swain, of the Institute, who spoke of the Water Power of the Southern Atlantic Slope of the United States.

Mr. Swain gave a brief description of the general structure of the Appalachian Mountain system, and a comparison between the character of the streams in the northern and southern portions. His remarks had reference only to that part south of the James River. The total area of the region studied was about 117,350 square miles, with an average width of about 240 miles. The rivers are navigable from the ocean in many cases nearly up to the point where falls are found, but are obstructed by sand bars and snags to a considerable extent. Upon the maps exhibited a line was drawn through the lowest points at which falls occurred on the streams. Between this "fall line" and the sea there is no water power, and the streams are sluggish. From this line to the sources of the streams are located all the powers.

In the discussion of the amount and value of the various powers it is necessary to know something of the amount of water flowing in the stream. As few measurements of this sort have been made on these southern rivers, considerations as to the amount of rainfall and the nature of the soil must be used in making these estimates. Charts show the amount of rainfall in various parts of the region were shown. The rainfall is often greater in this region in winter than in summer, but at that time the evaporation is less rapid, and hence the streams would receive the greatest addition when least needed, and would thus be more variable than the rivers of the northern region. The absence of lakes and the rapid removal of the forests also contribute to render these streams more irregular in flow. As there are no considerable falls of snow and no great formations of ice, the southern streams would be comparatively free from spring freshets.

The facilities for artificial storage basins in this region are not particularly great, as in many cases the valleys which must be overflowed compose the best farming lands.

The convenience of transportation is an important consideration in the estimate of the value of a power, and the location of the railroads at present is somewhat unfavorable. The topography of the region is such as to render it easier to secure a good location for the railroads upon the divides or ridges separating the streams than along the valleys. Hence many of the falls are at a distance from the roads.

The following brief list of some of the most notable powers, most of them undeveloped, will show, however, that there is a very large amount of available power upon these streams. The figures are given only for the most important powers, and are computed from approximate figures for the dryest season of a year dryer than the average:

The Roanoke River has at one place a fall of about 84 feet in nine miles, which could furnish about 18,500 horse-power.

The Dan River, at Danville, Va., has a

fall of 22 feet, capable of furnishing 1200 horse-power.

The Tar, at Rocky Mount, has a fall of 20 feet, with 350 horse-power.

The Cape Fear has, at Smiley's Falls, 27 feet fall in 3½ miles, with 2850 horse-power, and at Buckhorn Falls 20 feet fall, with 2000 horse-power. The Deep and Haw rivers are the most utilized of the streams of North Carolina. The former has eight cotton factories, and has a fall of 24 feet at Lockville, giving 800 horse-power, which is partially utilized. The Haw carries seven cotton factories. Both have several powers not utilized.

A very remarkable gorge exists at the Narrows of the Yadkin River, where there is a fall of 150 feet in 3½ miles, which could furnish 15,000 horse-power, but owing to the precipitous nature of the banks cannot be made available. At Bean's Shoal is a fall of 39 feet in four miles.

Upon the tributaries of the Santee are several fine powers. Of these the Wateree has falls of 42 feet, 173 feet, 35 feet, and 25 feet; the Congaree, at Columbia, S. C., one of 22 feet; the Broad and Lockhart shoals one of 46 feet in 1½ miles, and at another point one of 102 feet in 6¼ miles; the latter is, however, enclosed by rather steep banks. Upon the tributaries of the Broad are many more smaller powers.

At Augusta, Ga., is one of the best powers in the South. The Savannah River there has a fall of 50 feet from the Augusta Canal, seven miles long. Of this fall 33 feet are utilized, capable of furnishing 9000 horse-power, of which but a portion is now used. At Trotter's Shoals is a fall of 75 feet in seven miles, and in the upper tributaries are many smaller falls.

The Altamaha River has on its tributaries many powers but little used.

ON THE STRENGTH AND OTHER PROPERTIES OF CUBAN WOODS.

AN INVESTIGATION OF THE STRENGTH AND OTHER PROPERTIES OF CUBAN WOODS USED IN ENGINEERING CONSTRUCTION, CONDUCTED IN THE MECHANICAL LABORATORY OF THE DEPARTMENT OF ENGINEERING OF THE STEVENS INSTITUTE OF TECHNOLOGY.

By ESTEBAN DUQUE ESTRADA, M. E.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

I.

INTRODUCTION.

The timber trees of Cuba, like those of every tropical country, are remarkable for their great size, both in diameter and height, their almost perfect indestructibility by those agents which ordinarily injuriously affect timber, such as insects, dry-rot and decay generally, their hardness and homogeneousness, the beauty of their texture and grain, and the fragrance of their wood.

As a class, they are but little known in the United States, a few varieties only being imported, such as lignum-vitae, rosewood, ebony, various kinds of cedar, and the several varieties of mahogany. The extended use of hardwoods in interior and exterior house-decoration will, it is thought, greatly increase the demand for certain valuable Cuban woods. The whole subject has a special interest and value to the writer, these being woods with which he is familiar, and he has ventured to take the subject of the strength of certain Cuban woods as a subject for investigation. It was decided to confine the investigation to comparatively few of the more important and representative types of timber, on the natural supposition that the slight differences between the several varieties would not seriously affect the general conclusions to which such experiments would generally lead.

In procuring these woods the writer had the good fortune to secure the co-operation of Mr. Alfredo Leblanc, of Cienfuegos (Cuba), who carefully se-

lected such pieces as, in his judgment, would best represent the useful, rather than the merely ornamental, "timber trees." These carefully-selected specimens probably represent as good an average as could be obtained by proper inspection.

The writer regrets very much that lack of time would not permit him to make these series of experiments complete in every detail.

The experiments by transverse and torsional stress are, it is hoped, as complete as they can be made; not so complete, however, are the experiments by compression, and especially by tensile stress. In studying up the subject the writer found little or nothing of value bearing upon any experimental determinations of the mechanical properties of the woods of Cuba.

Description of Woods.

Baria (*Cordia gerascanthoides*) attains a height of about 60 feet (18.3 meters), and a diameter of 18 inches (46 centimeters) and often more. It is found in nearly all parts of the island, being more abundant towards the central part.

The wood has a dark greenish brown color in the heart, and is lighter in the sap-wood. It is highly prized on account of its strength, durability and lightness. The wood when varnished has a very handsome appearance. It is extensively used in framing, carriage making, and general house-fitting. Its specific gravity is 0.78.

Caobilla (*Crotos lucidam*) is said to be a variety of the Caoba (*Swientenia mahogani*). It grows on black soils, and near the coast. It attains a height of 40 feet (12.1 meters), and is quite abundant. The wood is light red in color in the heart and brown white in the sap wood; is fine grained, and, as a general rule, is inferior in strength and durability to mahogany. It is chiefly used for furniture, boarding and framing. Its specific gravity is 0.80.

Cocullo (*Bumelia nigra*) is found on hills and rocky lands. It attains a height of 50 feet (15.2 meters). It has many branches, has but little sap-wood, and can be obtained in considerable quantities.

The wood is strong, heavy and elastic, and is yellowish white in color. It has a different appearance when seen across the grain, being dotted with white spots. It is used for cart constructions and buildings, is very durable, and can be worked moderately easy. It can be obtained in logs 12 inches (30.5 centimeters) square. Its specific gravity is 1.15.

Dagame (*Colycophyllum candidissimum*) is one of the most plentiful trees of the forests of Cuba, being generally found near mountains, and in reddish soils. A common height is from 40 to 50 feet (12 to 15.2 meters). Its trunk is straight and quite free from branches.

The wood is of a pale yellow color, very fibrous, is close grained, thus resembling box-wood; is moderately heavy, and very strong and elastic. It is very easily worked, either across or with the grain. It turns remarkably well, is entirely free from knots, and susceptible of good polish; it is very durable.

It is used very extensively in general carpentry, for the wood-work of plows, cart axles, spokes and spikes; is an excellent material for house-framing for its strength and durability, and joiners prefer it for their work to most other woods. It is also very extensively employed by carriage manufacturers, for ships' yard-arms, and other similar purposes. The largest section that can be obtained after squaring is 12 inches (30.5 centimeters). Its speciffc gravity is 0.90.

Guayacancillo (*Guaiacum verticale*), is very much like the Guayacan (*Guaiacum officinale*), or what is known in this country as lignum-vitæ, and appears to be one of its varieties, its dimensions being smaller than those of the latter, and its leaves fewer in number. It is found quite abundantly along the road to Puentes Grandes, which furnishes the main supply. The largest logs that can be obtained from this tree are from 10 to 20 feet (3 to 6.1 meters) long, and 6 to 10 inches (3 to 6 centimeters) square.

The wood is light yellow in the sap-wood, and dark brown in the heart, sometimes with dark green shades. The other properties and its uses are exactly those of the lignum-vitæ, with this exception that the guayacancillo has a higher modulus of rupture and coefficient of elasticity. It hardens upon exposure to the air. In Cuba it is chiefly employed for sheaves of pulley-blocks, or water-wheels, and for all the uses to which lignum-vitæ is put. Its specific gravity is 1.08.

JIQUI COMUN (*Bumelia nigra*) is found in large supply, especially in the center part of the island, where it abounds in all kinds of soil. It attains the height of from 50 to 70 feet (15.2 to 21.3 meters). The largest section obtainable after squaring is 18 inches (46 centimeters).

The wood is one of the hardest known, is exceedingly heavy, fine grained, and very compact. It has a rosewood color, and becomes harder and darker with age, and when very old it is almost black, and is very difficult to work. It is principally used for posts, in consequence of its great durability and strength, and is a very fine material for dock-piles, owing to its non-liability to decay; is not attacked by insects, and it is said that it petrifies under water. It is also used for telegraph poles, piles for foundations, scaffolding, railings, and main posts for gateways. It turns easy, and with good tools it can be made of any desired shape. Its specific gravity is 1.20.

JOCUMA AMARILLA (*Sideroxilon solicifolia*) grows preferably on rocky soils, and is largely found near the coast; it reaches a height of 60 feet (18.2 meters), and furnishes logs of 16 (40.6 centimeters) after squaring.

The wood is of a light yellow color, heavy, fine grained and strong; is entirely free from knots, cup or star shakes, and works well. It is largely used in framing, for beams, tiles and posts, cabinet work, and general building constructions. Its specific gravity is 1.04.

JUCARO PRIETO (*Bucida*) is found in large supply near the southern coast, and attains a height of from 60 to 80 feet (18.2 to 24.3 meters), for which it requires 50 to 55 years growth; it has lateral roots, and yields gum by incision.

The wood has a dark brown color, much resembling black walnut, is very strong, tough and elastic, is heavy, fine grained, and free from knots. It stands the weather remarkably well, is worked easily, and is susceptible of good polish, thus producing a handsome effect.

It is largely employed in naval constructions, for purposes where strength and durability are required. It is also very extensively used by millwrighters, and is an excellent material for posts, piles, and general dock constructions. It can be obtained in logs of 36 feet (10.9 meters) length, and 16 inches (45.7 centimeters) square. Its specific gravity is 1.08.

JUCARO MASTELERO (*Bucida*) is found on low lands and valleys. It attains a height often exceeding that of the jucaro prieto, which is one of its varieties. Its fruit is of great value for cattle food. It is very abundant on the low lands of Camaguey. The wood has a light yellowish brown color, is very strong, hard and elastic; it has very little sap-wood, and is readily worked. It is used very much in naval constructions, for railroad ties, framing, millwrights' work, and for cart axles it is given the preference. It can be obtained in logs 16 inches (45.7 centimeters) square. Its specific gravity is 0.89.

MAJAGUA AZUL (*Paritium elatum*) is very abundant, reaching a height of 50 feet (15.2 meters), and often more. It attains a great age. The forests of Camagüey and Vuelta Abajo abound with this tree. Logs of from 16 to 20 inches (45.7 to 50.8 centimeters) square are very common. The trees growing in dry and rocky soils give the best timber, so far as strength and elasticity are concerned.

The wood is used for ships' ribs and framing, planks and boards, carriage work, furniture and gun-stocks. The bark of this tree furnishes an excellent material for ropes and hawsers, being particularly valuable because so little affected by dryness or dampness.

The wood is very easily worked, closely resembing the white pine of this country in this respect. In color it is of a deep greenish blue from which property it derives its name. Its specific gravity is 0.72.

MAJAGUILLA (*Carpodiptera cubensis*) is found in Buelta-Abago; attains a height of from 40 to 50 feet (12.1 to 15.2 meters), and its bark is of great value for the manufacture of rope.

The wood is hard, heavy and strong; it is quite resinous, and consequently difficult to work. Its color is yellowish red. It is principally used for posts, carts and other constructions where finish is not of great importance. The largest section obtainable is 14 inches (35.5 centimeters). Its specific gravity is 1.11.

OCUJE MACHO (*Calophyllum calaba*) is of straight growth, attaining a height of from 50 to 60 feet (15.2 to 18.2 meters); its trunk is long and straight. It is very plentiful in the forests of Camagüey.

The wood is said to be indestructible, comparatively light, of a fibrous texture, and of a reddish color. This wood is highly valued in carpentry and rural constructions; is an excellent material for piles, for which purpose it is very extensively used; it is also used for spars and general ship construction, cart axles, and millwrights' work, Its specific gravity is 0.84.

Quiebra-hacha (*Copaifera humenaefolia*) is found in great abundance along the southern coast of the island, where it attains a height of upwards of 50 feet (15.2 meters) and considerable diameter; it has very little sap-wood, and makes an excellent timber.

The wood is of a dark red color, very much resembling the darker kinds of mahogany. It is exceedingly hard and heavy, and yet is not very difficult to work. It has no equal for use under ground and under water; is perfectly safe against the attacks of insects, of decay, and petrifies under water. Its hardness increases with age, and its color also becomes darker. It is used for all kinds of posts, railroad ties, piles, dock beams, engine foundations, and framing for heavy machinery. It can be obtained in logs as large as 24 inches (61 centimeters) square. Its specific gravity is 1.30.

Sabicu (*Mimosa adorantisima, Vel Acacia formosa*) is plentiful throughout the island, and attains colossal dimensions. It abounds chiefly on rocky and sandy soils. Its growth is somewhat crooked and irregular, but it yields an excellent timber of from 30 to 40 feet (9.1 to 12.1 meters) long, and up to 36 inches (92 centimeters) square. It has very little sap-wood, and its bark is an excellent material for tanning. The wood has a dark chestnut color, and is often twisted or curled in the fibers, sometimes very much resembling rosewood. It is hard, heavy and strong. It is very durable, and when entirely free from the sap-wood it is not affected by insects, even when left unprotected by paint. It works remarkably well across or with the grain.

The wood is used in shipbuilding, not only in Cuba, but also in England and Spain, for beams, keelsons, engine-bearers, and stern-posts, pillars, cleats, and for various other similar uses. In Cuba it is principally used for posts, dock constructions, millwrighting, and to nearly all the uses to which the quiebra-hacha is put. Its specific gravity is 0.95.

Yava (*Andira inermis*) is very common, especially in reddish soils; it attains a height of 60 feet (18.2 meters), and reaches a great age.

The wood varies very much in color, which leads to the belief that there are different species, and yet they belong to the same family. Some specimens of it resemble very much in their color the yellow pine of this country. It is very hard, strong and durable. It is used in millwrighting, for wheel segments, spokes, &c. It is very valuable for ship constructions, especially for keels, rudders and boarding. The largest section obtainable after squaring is 16 inches (40 centimeters). Its specific gravity is 0.88

Description of Testing-Machines.

The testing-machines used in these experiments were the standard machines used of the Mechanical Laboratory of the Department of Engineering of the Stevens Institute of Technology, and are fully described by Prof. R. H. Thurston, in his paper on the "Strength of American Timber," as follows:

The Tension and Compression Machine consists of two strong cast iron columns, secured to a massive bed-frame of the same material; above these columns is fastened a heavy cross-piece, also of cast iron, containing two sockets, in which rest the knife-edges of a large scale beam. The upper chuck is suspended by two eye-rods from two knife-edges $\frac{1}{2}$ in. to one side of center of a heavy wrought iron block, which is hung by two links from two pairs of knife-edges projecting from the scale beam on opposite sides of the knife-edges of the latter, and at equal distances from them, the whole making a very powerful differential beam combination. All the knife-edges are of tempered steel and the sockets and eyes are lined with the same material, thus reducing friction to a minimum. The stress is applied by means of a hydraulic press, with a fixed plunger and movable cylinder; to the latter the lower chuck is fastened by means of an adjustable staple and link. The stress to which the test-piece is subjected is measured by means of suspended weights and a sliding poise not seen in the figure. The specimen is secured in the chucks

either by wedge-jaws or cord chucks, according to the specimens to be tested. The capacity of the machine (Fig. 1) is twenty tons.

The extensions are measured by means of an instrument in which contact is indicated by means of an "electric contact apparatus." The instrument consists essentially of two very accurately made micrometer screws, working snugly in nuts is made between the two insulated points and one pole of a voltaic cell, and also between the micrometer screws and the other pole. As soon as one of the micrometer screws is brought in contact with the opposite insulated point, a current is established, which fact is immediately revealed by the stroke of an electric bell placed in the circuit. The pitch of the screws is 0.02 of an inch, and

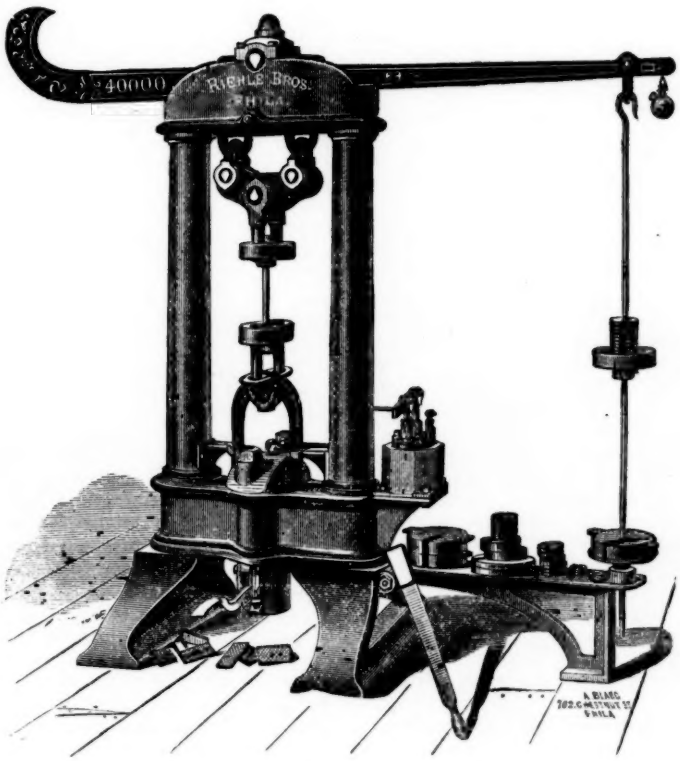


FIG. 1.—TENSION AND COMPRESSION MACHINE.

secured in a frame which is fastened to the head of the specimen by a screw clamp. It is so shaped that the micrometer screws run parallel to and equidistant from the neck of the specimen on opposite sides. A similar frame is clamped to the lower head of the specimen, and from it project two insulated metallic points, each opposite one of the micrometer screws. Electric connection their heads are divided into 200 equal parts; hence a rotatory advance of one division on the screw head produces a linear advance of one ten thousandth (0.0001) of an inch. A vertical scale divided into fiftieths of an inch is fastened to the frame of the instrument, and set very close to each screw head and parallel to the axis of the screw; these serve to mark the starting point of the former,

and also to indicate the number of revolutions made. By means of this double instrument the extensions can be measured with great certainty and precision, and irregularities in the structure of the material, causing one side of the specimen to stretch more rapidly than the other, do not diminish the accuracy of the measurements, since half the sum of the extensions indicated by the two screws is always the true extension caused by the respective loads.

ment for measuring the deflections is not shown in the cut; it consists of an accurately cut micrometer screw of steel, having a pitch of 0.025 of an inch, working in a nut of the same material mounted in a brass frame. This instrument is supported by a rod of considerable rigidity and of sufficient length, which is secured to the beam C, close to the tension rods FF, in such a manner that the micrometer is directly under the cross-head, in the same vertical plane with the test-

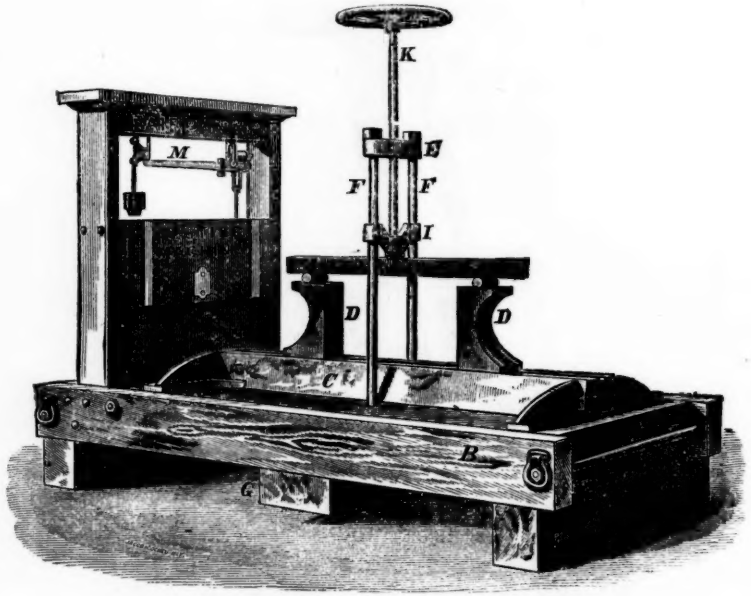


FIG. 2.—TRANSVERSE TESTING MACHINE.

The Transverse Testing-Machine (Fig. 2) consists of a Fairbanks scale, on the platform of which rests a heavy cast-iron beam C, to which are fastened the supports DD at the required distance apart. The pressure is applied by means of the band wheel on the upper end of the screw K, which screw passes through the nut E, and terminates in the sliding cross-head I. This cross-head serves both as a guide and as a pressure block. The test-piece L rests upon mandrels mounted upon the supports DD at the required distance apart. The loads are weighed in the usual manner at M. The instru-

piece, and very near and parallel with the axis of the large screw K. The micrometer screw is provided with a head which is divided into 250 equal parts. Thus a rotatory motion of one division produces an advance in the direction of the axis of the micrometer screw of 0.0001 of an inch. A scale divided into fortieths of an inch is fastened to the frame of the instrument, in close proximity to the head and parallel to the axis of the screw; it serves to mark the starting point, and indicates the number of revolutions made in taking a measurement with the screw. To insure accurate

readings of the deflections the principle of the electric contact is also employed here. The capacity of the machine is 7,000 pounds.

Prof. Thurston's Autographic Machine (Fig. 3) consists of two strong cast-iron wrenches facing each other with a space of 1¼ inches between their jaws. They rotate in independent journals placed in the same lines in the frames; the latter are bolted to a heavy bed-plate, which gives it the required stability. One of the wrenches is provided with an arm 4.5 feet in length, at the lower end of which is attached a heavy weight B; the other wrench has keyed to it a worm-wheel engaging with the worm which is set in motion by means of a crank. In this manner a very slow and quite uniform motion can be obtained.

FIG. 3.—AUTOGRAPHIC MACHINE.

Both wrenches are provided with lathe-centers directly opposite each other and in the common axis of rotation. The specimen to be tested is placed upon

the lathe-centers, which hold it in line while it is being secured in the jaws of the wrenches by means of steel wedges inserted from opposite sides. On the shaft of the wrench carrying the worm-wheel there is fastened a brass drum which rotates with it, while to the other wrench is fastened a pencil-holder which allows the point of the pencil to move on the surface of the drum, and is guided by the stationary curve of brass, in such a manner that its position on the drum indicates the number of foot-pounds of moment exerted by the arm and weight at any instant.

Supposing a test-piece to be placed in the machine the operator turns the crank with a uniform velocity, which gives a slow and a very steady motion to the wrench connected with the worm-wheel, which is transmitted through the test-piece through an arc which is a measure of the resistance to torsion offered by the test-piece, and is recorded simultaneously with the angle of torsion by the pencil upon a diagram-sheet fastened upon the drum for the purpose. The drum is of such a diameter that the circumference is 36 inches, which, when divided into tenths, makes 360 divisions, each of which is representative of one degree. The guide curve is a curve of sines, which insures the position of the pencil on the drum always such that it marks an ordinate proportional to the moment of the arm and weight at every instant during the test. The friction of the machine is not recorded by the machine but is added in calculating the results.

Dimensions and Form of Test-Pieces.

In preparing the test-pieces it was endeavored to make them conform as nearly as possible to the standard shapes and sizes of the Mechanical Laboratory. This could only be done in the case of the torsion specimens. Since the size or length of the test-specimen ought not theoretically to affect the strength of the wood, it was deemed safe to make the transverse specimens as large as possible.

In preparing the test-pieces for the tensile tests it was found necessary to provide against the shearing or crushing of the pieces in the chucks of the testing-machine. The test-pieces were prepared, viz., 1.5 inches (3.81 centimeters) wide, 1 inch (2.54 centimeters) thick, and 14 inches (35.5 centimeters) long, a hole 1 inch (2.54 centimeters) in diameter was then drilled at a distance of three inches (7.62 centimeters) from each end, or as much as the yoke of the machine would permit; it was found, however, that this distance of three inches thus available at the upper end was not sufficient to prevent shearing. Thus the experiments for tension are incomplete, and but few are reliable.

The compression specimens were made as large as the capacity of the machine would allow, always preserving the proper ratio of length to diameter.

Experiments to Obtain the Modulus of Elasticity by Transverse Stress.

The coefficient of elasticity for transverse resistance was obtained in the following manner: Each specimen was planed to a square section and to the largest size which its original dimensions permittted; then the breadth and depth were accurately measured by means of a micrometer screw reading to the 0.001 of an inch, after which it was placed on the transverse testing-machine, fixing the supports so as to allow 2 inches (5.08 centimeters of the test-piece to project beyond them. The beam being carefully balanced, the weight of the piece included, a load of 50 pounds (226.8 kilogrammes) was applied each time up to 200 pounds (907.18 kilogrames), and the corresponding deflections measured by means of the apparatus previously described. In most cases the deflections were directly proportional to the loads, and where any difference occurred it was exceedingly small. Several pieces were tried of different lengths, and the results obtained were accordant.

The formula used in these determinations was $E=\frac{Pl^3}{48\,\Delta\,I}$, where P represents any load within the elastic limits, l the distance between the supports, Δ the corresponding deflection, and I the moment of inertia which, for a rectangular section, equals $\frac{1}{12}\,bd^3$.

Modulus of Elasticity by Transverse Stress.

Woods.	Length in inches.	Breadth in inches.	Depth in inches.	Loads in pounds.	Deflections in inches.	Difference in inches.	Modulus of Elasticity per formula $E = \frac{Pl^3}{4Dbd^3}$
Baria I_1.	36	1.78	2.00	50	.023	.023	1700000
				100	.046	.023	
				150	.069	.023	
				200	.092	.023	
Baria I_2.	36	1.50	2.00	50	.026	.026	1790000
				100	.052	.026	
				150	.078	.026	
				200	.104	.026	
Baria I_3.	36	2.10	2.12	50	.018	.018	1620000
				100	.036	.018	
				150	.054	.018	
				200	.072	018	
Caoba.	28	1.72	2.65	50	.006	.006	1429166
				100	.012	.006	
				150	.020	.008	
				200	.026	.006	
Caobilla.	30	1.46	2.50	50	.008	.008	1849315
				100	.016	.008	
				150	.024	.008	
				200	.032	.008	
Cocuyo K_1.	40	2.15	2.04	50	.019	.019	2310469
				100	.038	.019	
				150	.057	.019	
				200	.078	.019	
Cocuyo K_2.	40	1.97	2.01	50	.021	.021	2200000
				100	.042	.021	
				150	.063	.021	
				200	.084	.021	
Cocuyo K_3.	40	2.16	2.00	50	.017	.017	2130000
				100	.034	.017	
				150	.051	.017	
				200	.068	.017	
Dagame J_1.	40	2.06	2.18	50	.015	.015	2500000
				100	.030	.015	
				150	.045	.015	
				200	.060	.015	
Dagame J_2.	40	1.94	2.28	50	.015	.015	2280820
				100	.030	.015	
				150	045	.015	
				200	.060	.015	
Dagame J_3.	40	1.50	2.03	50	.027	.027	2361623
				100	.054	.027	
				150	.082	.028	
				200	.110	.028	
Dagame J_3.	40	2.03	1.50	50	.048	.048	2433460
				100	.096	048	
				150	.143	.047	
				200	.192	.049	
Guayacancillo.	82½	1.50	2.59	50	.007	007	1503561
				100	.014	.007	
				150	.021	.007	
				200	.028	.007	
Jocuma Amarilla G_1.	36	1.54	1.55	50	.043	.043	2250000
				100	.086	.043	
				150	.133	.047	
				200	.177	.044	
Jocuma Amarilla G_2.	36	1.47	1.61	50	.062	.062	2300000
				100	.119	.057	
				150	.186	.067	
				200	.243	.057	
Jiqui Comun E_1.	28	1.82	2.00	50	.0075	.0075	2520952
				100	.0150	.0075	
				150	.0225	.0075	
				200	.0300	.0075	
Jiqui Comun E_2.	28	1 90	2.35	50	.000	.005	2490272
				100	.015	.000	
				150	.010	.005	
				200	.025	.000	
Jiqui Comun E_2.	36	1.90	2.35	50	.010	.010	2490000
				100	.020	.010	
				150	.030	.010	
				200	040	.010	
Jiqui Comun E_2.	40	1.90	2.35	50	.013	.013	2490000
				100	.026	.013	
				150	.039	.013	
				200	.052	.013	
Jiqui Comun E_3.	28	1.87	1.87	50	.009	.009	2490000
				100	.008	.009	
				150	.027	.009	
				200	.036	009	
Jucaro Mastelero B_4.	40	1.81	1.83	50	.044	.044	2000000
				100	.088	.044	
				150	.132	.044	
				200	.176	.044	
Jucaro Mastelero B_5.	40	1.56	1.50	50	.056	.056	2500000
				100	.118	.052	
				150	.183	.065	
				200	.248	.065	
Jucaro Prieto B_6.	28	1.29	1.68	50	.019	.019	2300000
				100	.038	.019	
				150	.056	.018	
				200	.074	.018	
Jucaro Prieto B_1.	28	1.50	1.81	50	.014	.014	2200000
				100	.028	.014	
				150	.042	.014	
				200	.056	.014	

MODULUS OF ELASTICITY OF TRANSVERSE STRESS—*Continued.*

Woods.	Length in inches.	Breadth in inches.	Depth in inches.	Loads in pounds.	Deflections in inches.	Difference in inches.	Modulus of Elasticity per formula $E=\frac{Pl^3}{4Dbd^3}$
Jucaro Prieto B_2.	28	1.45	1.75	50	.016	.016	2195200
				100	.032	.016	
				150	.050	.018	
				200	.068	.018	
Jucaro Prieto B_3.	28	1.50	1.87	50	.014	.014	1995636
				100	.028	.014	
				150	.042	.014	
				200	.056	.014	
Majagua Azul D.	28	1.65	1.88	50	.0135	.0135	1939393
				100	.0260	.0125	
				150	.0390	.0130	
				200	.0525	.0135	
Majagua Azul D_3.	28	1 98	2.12	50	.007	.007	2000000
				100	.014	.007	
				150	.021	.007	
				200	.028	.007	
Majaguil-la L_2.	40	1.66	2.12	50	.020	.020	2000000
				100	.040	.020	
				150	.060	.020	
				200	.080	.020	
Majaguil-la L_3.	36	2.25	2.31	50	.010	.010	2257548
				100	.019	.009	
				150	.028	.009	
				200	.037	.009	
Ocuje.	28	1.38	1.64	50	.030	.030	1500000
				100	.060	.030	
				150	.090	.030	
				200	.120	.030	
Sabicu A_1.	28	1.22	1.82	50	.015		2486070
				100	.030		
				150	.045		
				200	.060		
Sabicu A_4.	28	1.21	1.59	50	.025	.025	2300000
				100	.050	.025	
				150	.075	.025	
				200	.100	.025	
Sabicu A_5.	28	1.25	1.76	50	.012	.012	2400000
				100	.024	.012	
				150	.036	.012	
				200	.048	.012	
Quiebra-hacha C_1.	28	1.43	1.78	50	.016	.016	2100000
				100	.032	.016	
				150	.048	.016	
				200	.064	.016	
Quiebra-hacha C_2.	28	1.73	1.76	50	.014	.014	2100000
				100	.028	.014	
				150	.042	.014	
				200	.056	.014	
Yava H_1.	40	1.51	1.54	50	.063	.063	2322463
				100	.125	.062	
				150	.187	.062	
				200	.249	.062	
Yava H_2.	40	1.50	1.51	50	.065	.065	2393258
				100	.130	.065	
				150	195	.065	
				200	.264	.069	
Yava H_3.	40	1.50	1.51	50	.065	.065	2393000
				100	.130	.065	
				150	.196	.066	
				200	.262	.066	

THE DEFINITION OF FORCE.

From "The Engineer."

FORCE is a something of which most people think they have had experience, and which to an engineer in particular is the very element in which he moves. It may well seem strange, therefore, that doubts should still exist as to its proper definition. Yet that there are such doubts it is impossible to deny. There are, in fact, at the present moment three separate schools of thought on the subject. Two of them are products of these latter days—equally bold and positive in their novel views, but wholly irreconcilable with each other. The third represents those who are content *stare super antiquas vias*, and to retain the definition which satisfied their fathers, but who, nevertheless, are quite aware that their friends of the new light—or lights rather, possibly somewhat interfering with each

other—regard them as sunk in worse than Egyptian darkness.

The first of these new schools shelters itself under the ægis of Mr. Herbert Spencer. That gentleman, ever since he published his "First Principles," has claimed a high place amongst the authorities on mechanical science; and this claim seems to be most readily admitted in all those circles where mechanical science is least understood. Now it is not too much to say that, in the eyes of Mr. Herbert Spencer, force is everything, and everything is force. The Persistence of Force is the one great, unquestionable, all-embracing principle, which explains all other principles, including evolution itself, and is the foundation and essence of the physical universe. True, Mr. Spencer does not anywhere define the persistence of force. But so far as we can gather, the persistence of force means that the forces of nature are continuous, not discontinuous; that they are always in action, not sometimes acting and sometimes quiescent. If we go further, and ask for a definition of force, we fear that neither will this be forthcoming; but at any rate we may gather that force is reality, if not the only reality. For this definition, if we could get it, would be a most comprehensive one; it would embrace what we mean when we speak of the force of a sledge hammer, and also what we mean when we speak of the force of an argument. So at least we may gather from Mr. Spencer's disciples, if not from himself. The latest of these disciples appears under the name of Mr. Norman Pearson. This gentleman deliberately, and without a smile on his countenance, adopts the view just stated; and actually founds an argument for the immortality of the soul on the ground that the soul is a force, and that all forces "persist." It is true, he admits frankly, first, that he knows nothing at all about the force of the soul; and secondly, that, so far as he does know, it is a chemical force, resulting from special combinations of phosphorus with carbon, &c. Now, nothing can well be more certain, than that these processes of combination cease when the man dies and his brain turns to dust; but as the soul must of necessity persist, that only proves that the soul is a force of some other character. By parity of reasoning, the same will of course hold of other descriptions of force—say, the force of a conclusion, the force of a repartee; the force of a joke; nay, we are thereby emboldened to put all the force we can into this present article, in the assurance of thereby rendering it as immortal as ourselves.

The second party we have alluded to proceed in a wholly different fashion. Far from regarding force as everything, they regard it as nothing. The leader of the party in this country is Professor Tait, whose knowledge of mechanics, unlike that of the gentleman named above, will be most fully recognized where mechanics are best understood. Now Professor Tait has said repeatedly that we have no right to regard force as having any objective existence whatever. All we know is that bodies, under certain circumstances, alter their velocities at a certain rate, and this rate of change of velocity—or taking into account the mass of the bodies, their rate of change of momentum—is that to which Professor Tait gives the name of force. When we speak of force, all we mean, or ought to mean, is this rate of change of momentum. This, and only this, is what we have to investigate. On this view the persistence of force, which to Herbert Spencer is the first of all truths, becomes not only meaningless, but false; for if there is one thing clear, it is that all bodies are not continuously changing their relative velocities. Moreover, since force is only a rate of change of momentum, it ought to be possible to write a book on elementary mechanics without introducing the conception of force at all. Professor Tait recognizes this, and some little time ago he presented to the Royal Society of Edinburgh a sketch of the way in which such a book might be drawn up. How the Society felt after it we have not heard. We do not, of course, question for a moment that Professor Tait understood his own meaning. We will go further, and admit that if he could have got one of his hearers quietly by himself for an afternoon or so, he might have made him understand it also—say that he understood it, at any rate; but further than this we are not able to go. Nevertheless, Professor Tait has followers no less confident and enthusiastic than those of Mr. Spencer; and only a few weeks ago, in these columns, the as-

sertion was made that in physical science no other meaning can possibly be given to force than the rate at which momentum is transferred from one body to another.

Who shall decide, when doctors thus disagree? The humble student of mechanics, anxious to learn what the "men of light and leading" in his generation have to tell him about the ultimate principles of his science, stands by perplexed, embarrassed, perhaps at last a little indignant. We will not presume to offer him advice, but, as one brother recounts his spiritual experiences for the good of another, so we, as humble students also, may perhaps whisper to him how we have succeeded in taking comfort to ourselves. In the first place, we would suggest that he need not trouble himself much with the views of Mr. Herbert Spencer or his followers. They may be left with perfect confidence to time and to themselves. In the second place, as regards the school of Prof. Tait, we would ask him to look at an utterance coming, not from an enemy, but from a supporter, or at least a candid friend of the school in question. In the *Philosophical Magazine* for April, 1883, he will find a short note by Mr. Maxwell Close, in which he points out very clearly the manifold confusions, the almost inextricable jumble, in which the ordinary terms and conceptions of mechanics are involved, by the adherence to this wrong definition of force as the rate of change of momentum. Having read this article, our student will probably do one of two things—he will either give up mechanics in disgust, or he will take heart and resolve to see whether after all there is not some third definition which has been given for force, and which has been upheld by men with whom a student need not be altogether ashamed to agree. And he will be surprised to find that this is so. For instance, he may come across the following words: Force is an action exercised on a body tending to change its state either of rest or of uniform motion in one direction." This is a literal translation from a book called the "Principia," written—some time ago it must be confessed—by one Isaac Newton. Now, Newton is generally supposed to have known something of mechanics—in fact, a good many people are disposed to put him very near the head of mechanical philosophers. True, freshmen of Trinity College, Dublin, are said to prefer Salmon; the students of Edinburgh may thunder "Tait," and the Burschen of Germany may shout for Kant or Helmholtz. But all these, we are inclined to think, would put Newton next to their favorite hero; and therefore—as in the celebrated Greek election, where each man voted for himself first and Themistocles second—we may fairly forecast what would be the result of an unbiassed decision. But Newton's view of force, as we have seen, was quite different from either Spencer's or Tait's; and our student will be still more surprised to learn that this was not an antiquated superstition of his—that it has been largely held since, and by men not in themselves inconsiderable. Thus we read: "Force is that which tends to cause or to destroy motion, or which actually causes or destroys it?" This is the first sentence in "The Mechanical Principles of Engineering and Architecture," by Henry Moseley. Again, "Force is said to be whatever produces, destroys, or changes motion:" this is the definition of Whewell. Whewell and Moseley were not unknown in their day as students of mechanics; their fame even yet lingers among us. Coming down to more recent times, we find the definition of Newton restated as follows: "Force is an action between two bodies, either causing or tending to cause change in their relative rest or motion." These are the words of William Macquorn Rankine, to whom even Edinburgh students will not refuse a measure of respect. In like terms Harvey Goodwin—who is undoubtedly a mathematican, and when he wrote these words could not even be branded as a bishop—"Force in any cause which changes or tends to change a body's state of rest or motion." If he looks abroad he finds that Navier, Morin, and Redtenbacher measure force in kilogrammes; and whatever we take a kilogramme to be, it certainly is not a rate of change of momentum. Lastly, if he turns to the "Elements of Natural Philosophy" itself, he will be astonished to find that its distinguished authors, *nolentes volentes*, have delivered themselves in the following terms: "Force is any cause which tends to alter a body's natural state of rest, or of uniform motion in a straight line."

Fresh from this search our student will

be able to appreciate at its full worth the confidence which asserts that it is quite impossible in physical science to look at force in any other light than as the rate of change of momentum. He will assert humbly, but fearlessly, that it is quite possible; that, in fact, it has often been done; that better men than himself or his interlocutor have been content so to do; nay, perhaps his bad passions may get the better of him, and he may be led to declare that it is not he who lives in darkness, but rather in the light of truth, with Newton, and Whewell, and Rankine, and Thomson, and Tait.

The fact is, the whole question is simple enough to those who approach it from the right direction. Force is known to us in two ways—first, as exercised by ourselves upon other things; secondly, as exercised by other things upon us or each other. It is the second class of forces which is studied in mechanics. These forces, like everything else outside us, can only be known ultimately by their effects. The most special and obvious effect of force is motion, and it is the leading principle of mechanics that forces are proportional to the motions which they cause, these motions being measured by the momentum given to the bodies on which they act. So far, there is no room for difference of opinion. But it is easy to make a step further, and to say that forces are not only *proportional* to the changes of momentum they cause, but that they *are* those changes of momentum, and nothing else. It is this step which has been made by Professor Tait, or rather it would seem by his followers. Let us see how it is justified by an appeal to similar cases. We will take first an illustration furnished us by Mr. Maxwell Close in the article already referred to. Disease causes death, and the strength of different diseases, or of the same disease at different times and places, might be measured by the increased rate of mortality which they have induced; therefore, on these principles, we must define disease as being a rate of increase of mortality, and must demand that our medical literature should be re-written in order that it may square with this definition. Again, the burning of fuel under a boiler causes the evaporation of steam, and, other things being kept the same, the rate of evaporation in cubic feet per hour will be proportional to the quantity of fuel burned; therefore, we must say that fuel is the rate of evaporation of water per hour in a given boiler, that and nothing else; and our treatises on steam boilers must proceed on that supposition.

We may go on forever quoting instances to show the absurdity of the step thus confidently taken, but it is needless. Our opponents can really find only one thing to say. They may point out that we do not call disease an increase in death-rate, or fuel a rate of evaporation, because we know a good deal about disease and fuel over and above the particular effects which they thus produce. We will not stop to inquire what would be the force of this objection, if it were true—as is here tacitly assumed—that we know nothing of force except from the motions it causes. It is sufficient to observe that this assumption is obviously and absurdly false. As it has been well put to us, it would seem that these gentlemen can never have got wedged in a crowd. We know that force produces at least one thing besides motion, namely, pressure. In fact, in our persons we know it much oftener as the cause of the latter than of the former. To put this latter effect aside altogether, and insist on dealing with the former as the absolute and exclusive effect of force, is as unwarrantable in theory as it is absurd in practice. A definition of force which involves the statement that there is no force acting between oneself and the earth, no force between the jib of a crane and the weights hanging motionless from it, no force between a locomotive engine and the train which it is trying in vain to start—such a definition is actually worse than that absence of all definition which we find among the followers of Mr. Spencer. Like them, it may safely be left to itself; meanwhile, we shall be contented with that view of force which contented the men whose names are quoted above, and on which they and their compeers have reared the magnificent fabric which goes by the name of mechanical science.

A NEW electric arc lamp, the invention of Mr F. L. Willard, has appeared at the Fisheries Exhibition in London. The novelty consists in the device for holding and releasing the pendulum which controls the fall of the carbon.

SOLIDITY AND BREADTH IN ARCHITECTURE.

From "The Building News."

THE quality of solidity is one deservedly valued in architectural composition, though we have very little evidence of it in modern buildings, partly owing, it must be observed, to the prevailing practice of designing in elevation. We shall probably never know the real extent to which the old architects relied upon plans and models for producing their grandest expressions of formal beauty, though the little insight we have into their modes of working prove beyond a doubt that the elevation was never made use of in the manner it is now. Much of the superficial character of modern architectural work is due to the limited areas we have to build upon, which renders it necessary to make the boundary lines of our buildings straight, or nearly so. To save ground, the plan must have few projections or recessions, and any depth for play of light and shadow must be reduced to the smallest dimensions. It is upon this principle that architects perforce are content to work and to give us drawings of faces instead of solids. Alison, in the section of his work on the sublimity of forms, cites the rectangular as the most expressive of strength and contrast. "The great constituent parts of every building," he says, "require direct and angular lines, because in such parts we require the expression of strength and stability." Again, speaking of sublimity in form, he mentions "magnitude in height," and "magnitude in depth." Ruskin also in his "Seven Lamps of Architecture," Chapter III., observes, "the relative majesty of buildings depends more on the weight and the vigor of their masses than on any other attribute of their design; mass of everything, of bulk, of light, of darkness, of color, not mere sum of any of these, but breadth of them; not broken light, nor scattered darkness, nor divided weight, but solid stone, broad sunshine, starless shade." In this respect the Greeks excelled all other architects. All their forms were rectangular. Both in the plan and openings the right angle was the predominant element. One author, Mr. Garbett, remarks the square-headed openings and recesses had an expression of power we fail to observe in Gothic edifices. The same principle pervaded the abacus, the cornice, the architrave, and other parts of the Doric temple. "Until," says Ruskin, "our street architecture is improved, until we give it some size and boldness, until we give our windows recess and our walls thickness, I know not how we can blame our architects for their feebleness in more important work." Unfortunately, the elevational treatment of facades renders them more or less pasteboard imitations. In every set of competition designs we see flatness and fritter of surface. Want of recess or depth is one of the chief weaknesses of modern architecture. Mr. Garbett, among others, has pointed out the want of thickness of walls and recess or window reveals, and it is in these respects the competition system has been so prejudicial to good architecture. There is a natural desire on the part of competition draughtsmen to give their prespectives exaggerated depth of returns in excess of that absolutely shown on the scaled drawings. The walls and projections are made to look thicker and bolder than they are intended to be; and the result is disappointment when the designs are carried out. Everything has been taken with the scantiest allowance; the pilasters are mere strips, the window reveals are only a few inches in depth, and the porticoes or projections are the merest subterfuges for the realities which they are intended to represent in elevation. It is this apparent flatness of surface and want of contrast of surfaces that has robbed the river front of the Houses of Parliament of half its dignity and effect. The windows look like perforated openings in thick pasteboard, so little is the thickness of recess, or the distance to the glass. The perspective drawings showed recessed openings of considerable depth from the wall plane. But this shallowness of recess is common in buildings of the present day. A reveal of 4½in. is often seen in houses of large dimensions,

which for their size ought to have windows of at least 9in. or 14in. recess to the glass. A Pall Mall copy of a celebrated facade at Venice—namely, the Sansovino Library—is spoilt by the want of depth of reveal given to the windows. In the Pall Mall example there is only depth enough for the return of the pilaster; in the original the depth of return admits two columns and space between. At least a sixth of the width of opening ought to be set back as a return to the glass, so that a 5 ft. window or opening ought to have at least a 9 in. reveal. The question of depth or thickness of wall is, of course, governed by the principle of fitness in proportion. The height of a wall requires a certain thickness to give an apparent stability to it. so the width and heigth of an opening demands a certain depth of reveal. Vitruvius, in his treatise on Architecture, mentions ichnography, orthography, and scenography as necessary to design. The first is the representation of the ground plan of the building; the orthography is the elevation of the front, shadowed, and the last, scenography, is the art of representing the front and *receding* sides properly shadowed, the lines being drawn to their proper vanishing points. So that the most ancient writer on architecture has propounded the necessity of plan, elevation, and perspective—as equally requisite means of representing a building. Scenography—in other words, perspective—is the only method by which the element of depth or thickness can be expressed; but how few architects ever design their buildings in this manner, or if they do, exhibit them to a proper scale! Architecture is a thing of three dimensions, it must have length, breadth, and depth—in other words, soldity; but architects draw their designs as if they had only two: the third dimension is disregarded: even if it is shown, it is often purposely misrepresented. Variety and contrast of surfaces can be obtained only by showing extent of depths as well as surfaces. The magnitude and sublimity of St. Paul's Cathedral, the British Museum, the Royal Exchange, the Bank, Somerset House, and the fine towers by Wren, are attributable mainly to the element of a third dimension. What would they be if they were only facades, without depth of return or projections or quadrangle? The breaking up of plan is thought a means of obtaining the quality of solidity; but the expedient is very frequently carried too far. In Gothic buildings, the length of actual walling so broken up might have inclosed an area of double the size, and real solidity is sacrificed to picturesqueness. On the whole, it may be shown that buildings of rectangular form in plan have more solidity of effect than the same area broken up into small parts. The plan of St. George's Hall, Liverpool. is three parallelograms conjoined, and a central attic over the great hall. The magnitude and sublimity of this structure arise from its severe rectangular outline and fewness of parts. Here we have a facade of 400 ft. in length, with a portico of 16 columns 46 ft. in height. The projections are few, and both in plan and elevation the breaks consist of simple masses of square form. But a situation in a square is not always obtainable. It is not always possible to go round a building, or to see its depth and length at a glance, and seldom are more than two sides exposed. An architect who can exhibit two sides of his building may consider himself fortunate, as then he can impose two fronts on a spectator, and impress him by a depth as well as a frontage. But it is not often that the architect has the opportunity of exposing two fronts of a building; he is content to endeavor to impress the public by the length and height of his facade, he cuts it horizontally into stories, and piles order upon order. The projections and recesses are slight, and the depth of window reveals scarcely that of a plank. To cover this deficiency of solidity, the surface is strewn with ornament, and the facade under a strong sunlight becomes as expressionless as a face without characteristic features. There are few recent buildings in London which can show this quality of solidity. The City of London School on the Embankment, by its bold receding window fronts and the depth of columns and soffit of arched recess, is one of the few buildings in which the quality of solidity and depth of return has been made a feature.

Apparent thickness can be obtained externally by other means than those which suggest themselves to ordinary

builders. If thickness of wall cannot be made available, the windows can be set back within the area; the jambs of openings can be made to look solid by return pilasters or columns, with spaces between, not, as frequently seen, by shallow pilaster returns to the window frame. In many recent designs for buildings, we find the projections and recesses made so slight as scarcely to give a *raison d'etre* for the break. For example, a portico, or center, breaking forward a few inches looks a very insignificant effort for mere show sake. It is far better not to have broken the front at all. If a massive tower is introduced in the facade, there is reason for a decided projection; a very slight one becomes often exceedingly ridiculous. Solidity of appearance may be obtained by carrying up features, such as towers and wings, so as to exhibit the return sides of those parts. How much the modern architect may learn from the Greek and Gothic artist can only be seen by noticing the plans of their buildings. The severe, right-angled form of the Grecian temple and its features gave a solidity of effect to them; the peristyle imparted depth and shadow to the facades; while the deep buttresses and projecting transepts and portals of the Mediæval church served the same purpose by throwing bold shadows. From what we have said, it will be noted that there are at least two modes of imparting the effect of solidity to buildings. One is by a study of plan—that is, in making projections of parts and features, and observing the principle that the right angle is the most expressive of strength and power; the other plan is by recessing the windows and entrances, by intercolumnar shadows and buttress projections. We may wait vainly for improvements in these respects, until the designer is taught to learn the viewing of a building in perspective, a study of it in its three dimensions of length, breadth, and thickness, and not simply in orthographic projection. Architects who have been endeavoring to reproduce "Queen Anne" and Late Gothic have strangely fallen short of this power, the projections of overhanging stories, gables, and other features being often so small as to appear mere counterfeits.

The subject of solidity leads us to notice the want of "breadth" in our modern work—a quality sadly sinned against, if it is at all respected. By breadth, we mean that amount of plain surface rest for the eye or repetition of parts which a building requires to give it consistency. It is a very common fault of most designs that they are divided or broken up into a multiplicity of parts; the surface is frittered away by ornament and frivolous features, so that the unity of the composition is almost lost. Such an effect is commonly seen in Gothic villas, in which breaks of gables, bay windows, chimneys, and turrets occur in a promiscuous fashion. Even the breaking up of a front by orders or pilasters may be carried so far as to suggest feebleness in design. Pilasters or insulated columns may be placed too close to each other, and there seems to be a proper proportion to be observed in their introduction, as in all mere ornament, beyond which they become mischievous and utterly destructive to repose. Solidity and breadth are two qualities which are violated every day by designers of the English Renaissance and half-timber styles, and both proceed from the same error of not studying plan, and in the equal distribution of ornament over flat surfaces without regard to perspective, light, and shadow.

REPORTS OF ENGINEERING SOCIETIES.

AMERICAN SOCIETY OF CIVIL ENGINEERS.—Sept. 19th, 1883.—A discussion by Mr. Charles Douglas Fox, of London, Corresponding Member of the Society, "On the Increased Efficiency of Railways," was read by the Secretary.

Mr. Fox referred to the fact that English railway managers and engineers have long realized the great importance and economy of a thoroughly substantial road bed. The formation widths on their chief railways are now made 30 feet both in cuttings and on embankments for the double lines, and very great care is taken to thoroughly dry this formation in cuttings by deep ditches on each side, with earthenware drain pipes in them, and fill in with broken stone, or other dry material. The ballast consisting of broken stone, clean gravel, coarse sand, burnt clay or ashes, is not allowed to be less than one foot in thickness below the bottom of the tie. For lines of constant and heavy traffic, the bull head grade, double-headed rail, having a large top member for wear, and a very small bottom member, is found to be the best section for steel rails. The weight of these rails is 84 pounds per yard. The chairs are from 40 to 46 pounds each, and the rails are secured in them by keys of compressed oak. The tendency of the Eng-

lish companies is to expedite traffic, both passenger and goods, not by higher rates of speed, but by reducing the number of stoppages. The traffic lines are gradually quadruplicating their tracks, in some cases throughout, in others by sidings several miles in length. There is a very general feeling in England in favor of identifying the driver with his engine, and holding him responsible for its working. On some lines the name of the driver is conspicuously attached to the engine. Mr. Fox forwarded also the railway regulations of the English Board of Trade, which give very minute directions in reference to the construction and running of railways.

A paper by Mr. Wm. Howard White, M. Am. Soc. C. E., was also read upon the subject of "Railroad Bridge Floors." Mr. White advocates inside guard rails for the purpose of preventing, as far as possible, serious results from the derailment of wheels.

His reasons for advocating the inside guard rails are, that he considers them more efficient for the same height above the tie than the outside guard; that they can be placed so as to hold the wheel nearer the rail, particularly when the use of the snow plow is considered; that they can be more strongly secured at the ends for the purpose of drawing derailed wheels towards the rail, or to secure the ditching of a car which has gone too far to be safely drawn back; that they are more economical.

He considers that the ties should have five inches of clear distance between them.

The papers were discussed by Messrs. Wm. H. Paine, Cooper, Blunden and Bogart.

A paper by Mr. James Christie, M. Am. Soc. C. E., on Experiments on the Strength of Wrought Iron Struts, was read by the Secretary in the absence of the author. These experiments were made at the Pencoyd Iron Works for the purpose of determining the comparative resistances to compression of long and short struts of rolled angles, tees, beams and channel sections. The specimens were tested by four different methods, viz., with flat ends between parallel plates to which the specimen was in no way connected; with fixed ends or ends rigidly clamped to parallel plates, the plates substantially forming flanges to the specimen; with hinged ends, or both ends fitted to hemispherical balls and sockets or cylindrical pins; with round ends or both ends fitted to balls resting on flat plates. The specimens varied in length from six inches up to 16 feet and were selected to obtain a uniform character of material. The paper gave tabulated results of 299 experiments, and these results are illustrated by a number of diagrams. There were also results given of a number of tests of welded tubes. The general conclusions drawn from these experiments were as follows:

($\frac{l}{r}$ being length divided by least radius of gyration.)

When struts are short, say $\frac{l}{r}$ below 20, there will be no practical difference in the strength of the four classes, so long as reasonable care is taken to keep the center of pressure in the center of the strut. Hinged ended struts vary all the way from round ended up to flat ended in strength. If the hinges are pins of substantial diameter, well fitted, and exactly coincident with the axis of greatest resistance of the strut, the strength of the strut will be fully equal to that of a flat ended; but considering the impractability of maintaining this rigid accuracy, the average hinged struts, as compared with flat ended, will fall in strength as the length is increased until $\frac{l}{r}$ is about 250, when they will average one-third less resistance than flat ended. From this point they will gain comparatively until $\frac{l}{r}$ becomes about 500, when both classes will be practically equal. Fixed ended struts gain in comparative resistance from the shortest lengths upwards until $\frac{l}{r}$ becomes about 500, when they are twice as strong as either the flat or hinged ended.

Round ended struts continually lose in comparative resistance as the length is increased, when $\frac{l}{r}$ is about 340 they will be half as strong as hinged ended, and when $\frac{l}{r}$ is about 160, they will have only half the strength of flat ended.

The iron from which the tests were made exhibited the following resistances to direct compression, being the general results of several tests of small section fifteen inches long and secured in such a manner as to prevent lateral flexure.

With 30,000 lbs. pressure per square inch incipient permanent reduction of length was observed.

With 35,000 lbs. pressure per square inch failure of elasticity occurred, and marked permanent reduction of length.

With 50,000 lbs. per square inch a permanent reduction of length of three per cent. occurred.

With 75,000 lbs. a permanent reduction of ten per cent., and with 100,000 lbs. pressure per square inch a permanent reduction of twenty-eight (28) per cent. of the length.

The paper was discussed by Messrs. Theodore Cooper and Charles E. Enery, who both expressed the opinion that these experiments were of very great value, being made with material of uniform character, and in such a way that comparisons could be made directly between the different methods adopted in testing.

ENGINEERING NOTES.

A SINGULAR accident happened lately at Zell, Canton Zurich. A new iron bridge over the Joess had just been completed, and in order to test its stability three wagons laden with cotton were drawn across it, a number of the local authorities being on the spot watching the proceedings. As the wagons started the bridge yielded slightly to their weight, and they had hardly reached the middle when the entire structure collapsed, and wagons, horses, and spectators were precipitated into the

stream. Herr Ott, Mayor of Zell, was killed, and Herr Winkler, a member of the Great Council, and two other persons, one of them the engineer, were so badly hurt that they are not expected to recover. The breakdown is ascribed to the indifferent quality of the iron of which the bridge was constructed.

SUBMARINE EXPLORATION.—Signor Toselli is reported to have invented an apparatus for exploring the depths of the ocean without danger or inconvenience. It is about 25 feet in height, and constructed of steel plate with gun-metal castings. It is calculated to resist a pressure of 180 lbs. to the square inch, so as to be able to attain a depth of 65 fathoms. The internal space is divided into three compartments—at the bottom, a chamber capable of being enlarged or contracted by a flexible diaphragm, so as to increase or diminish the volume of water displaced, and thus permit of rising or sinking; a room capable of holding eight explorers, occupying the central portion of the spheroid, and provided with lenses, so as to permit of looking out; and the upper space, reserved for those entrusted with manœuvring the vessel. A powerful electric lamp is to shed its rays all round the apparatus for a considerable area, and telegraphic and telephonic wires will place those in the vessel in communication with the steamer from which it is suspended.

DEEPENING RIVERS.—It is well known that the Mississippi River gives a great deal of trouble, and it would appear that the losses and dangers incurred by floods are augmenting. We have long since pointed out in these pages that the proper way to prevent floods from doing harm is to lower the beds of the rivers instead of building embankments. American engineers begin at last to realize the fact that this theory is sound, and a scheme for lowering the bed of the great river is now being discussed. Mr. Erkson proposes the use of barges or deep-water boats from 500 ft. to 600 ft. long, so constructed as to be capable of being sunk and anchored to the bottom of the river, so as to create strong currents, and thus cut away bars or cut-off bends, and give a uniformity of current to the stream. The upper portion of the barges deflects the top or surface current of the river, and assists it in carrying off the obstructive matter which is raised. The barges can be taken up, it is said, and removed in two hours to some other place, or their positions can be entirely changed in a much shorter space of time, and by their use Mr. Erkson holds that rivers and bars can be ploughed to a depth of 30 ft. According to an American contemporary, this scheme has met with the approval of the United States Corps of Engineers. The idea is very ingenious, how far it is practicable must depend mainly on the river. There are, however, many places in which the use of movable obstructions would no doubt prove useful in causing the automatic modifications of river beds, and we commend Mr. Erkson's scheme to the attention of our readers without claiming more for it than that it is worth consideration and investigation. As regards the Mississippi, something must be done very soon. It is stated by the ablest and best informed engineers, that in a comparatively short space of time the Crescent City will be practically stranded, high and dry, thirty miles from the river, by its breaking through into Lake Ponchartrain; and Vicksburg and Greenville will each be twenty miles distant from the river bank. From Greenville to Memphis, the majority, if not all, of the plantations and villages will within twenty years be ruined. Within a shorter time Fort Randolph is in danger of being left fifteen miles from the river bank. The towns and plantations in the vicinage of Island No. 10 are in great danger of being destroyed, and Cairo, some engineers tell us, will shortly become a town on the Ohio River, twenty miles from the Mississippi. Even St. Louis, strange as it may seem, is in no little danger.

BRIDGING OVER THE STRAITS OF MESSINA.—Attention is called by the *Rheinisch Westfalische Zeitung* to a proposal of Signor A. Giambastiani for erecting a bridge over the Straits of Messina, instead of piercing the tunnel which has been for some time under discussion in Italy. His experience in designing bridges of extensive span has been, it is said, of a varied character, and he was chief engineer in the construction of the Italian approaches to the St. Gothard Tunnel. He proposes to have five openings, the three middle to be each 1,100 yards in length, and the two side openings to be each have that length. The pillars are to be of granite, and the openings will be spanned by arched girders of steel, the rise of which is designed to be one-tenth of the width of the arch. Signor Giambastiani intends, it is said, to perfect his design in accordance with the detailed local investigations he proposes to make, and then to place it before the Italian Minister of Public Works. With reference to this scheme, Herr Cottrau, director of the "*Impresa Industriale Italiana*," has called attention to the fact that the idea is not new, as he made studies for the same purpose in 1866. He had proposed openings of 650 to 875 yards, but after careful examination had arrived at the conclusion that the secure placing in position of solid pillars in the Straits of Messina was either impossible, or only practicable by means of an expenditure out of proportion with the results to be obtained. He founded this opinion on his investigations respecting the depth of the channel and the force of the current, and it was for this reason that the matter was then abandoned.

RAILWAY NOTES.

ELECTRIC TRAMCARS IN PARIS.—Some authentic facts have now been published about the recent trials of tramcars driven by storage batteries in Paris. M. E. Rouby, engineer of arts and manufactures, has furnished the data which we are about to give. The car propelled is of the large size, constructed by the Compagnie Générale des Omnibus de Paris. It contains fifty-two passengers, and was built for horse traction. M. Raffard, the engineer who had charge of the experiments, fixed the dynamo or motor (a Siemens D_2 type) under the

floor of the car near the platform. This dynamo received the current from eighty accumulators placed under the seats of the car. From this dynamo a belt and pulley, with differential movement controlled an intermediate shaft, which carried two pinions gearing with chains and toothed crowns carried by the wheels of the car. On June 24, a car with thirty passengers left the Place de la Nation at 4 A. M., and arrived at La Muette, near the gates of the Bois de Bologne *via* the external Boulevards, at 5.20 A.M. After half an hour's halt, it returned to La Nation by 7 A. M., having accomplished 32 kilometers with a mean speed of 11 to 12 kilometers per hour. The total weight of the car, with the eighty accumulators of 30 kilogrammes each, was about 9 tons. The mean current was 35 ampères at 160 volts E.M.F. The electric work furnished to the dynamo was, therefore, $\frac{35 \times 160}{746}$ = (about) 7 horse-power during 2½ hours, and the accumulators were still unexhausted. In the second experiment, at the Champs Elysées, the car went indifferently on the rails or macadamized road.—*Engineer.*

AT the commencement of last year Germany possessed 33,707 kilos.—1 kilo. = ⅝ mile—of railways of ordinary gauge, 192 of narrow gauge, and 1477 of mountain lines. Of this number 22,325 were owned and worked by the State, 3737 were owned by private companies, but worked by the State, while 7644 were owned and worked by private companies. The State possessed in Prussia 11,505 kilos., 4267 in Bavaria, 1942 in Saxony, 1535 in Wurtemburg, 1185 in Baden, 270 in Hesse, 278 in Oldenburg, and 89 in Saxe-Coburg-Gotha. But if we include all the private lines administered by the State, then we find that Prussia possessed about 15,000 kilos, almost half of the whole German system. The most important private company lines are those of Altona-Kiel, Berlin-Hamburg, Brunswick and the Palatinate. The cost of establishing the German railway system was 8400 millions of marks—£420,000,000—varying from 45,333 marks to 759,654 per kilo. The proportion of first-class traveling to second-class is 104 first in every 10,000 travelers, to 1355 second. The railway administration employs altogether about 300,000 persons, thus distributed: In the general management 7977, and 3457 temporary employés, with 840 artisans; on the lines themselves, 30,060 permanent and 2663 temporary employés, with a staff of 58,021 workmen; or, in round numbers, 90,143 persons, while the traffic necessitates a body of 72,555 employés and 55,852 workmen.—*Engineer.*

IRON AND STEEL NOTES.

ON SOME THEORETICAL CONSIDERATIONS CONNECTED WITH THE HARDENING AND TEMPERING OF STEEL.—By Professor Chandler Roberts, F. R. S.

The Cutlers' Company of London, have during the past few years, instituted a series of lectures in connection with the general scheme for technical education. The last of the series for the present session was delivered on Thursday, April 12, by Prof. Chandler Roberts, F. R. S., "On some Theoretical Considerations connected with the Hardening and Tempering of Steel."

He traced the history of the subject, and, quoting Guyton Morveau, said that Stahl, the great supporter of the Phlogistic theory, considerd that iron, "cemented" with carbon in closed vessels, gained phlogiston, and became in consequence steel; and this was the opinion of his disciples, who considered steel to be merely iron possessing the characteristics of a metal in a higher degree than iron, a view which will be found in the works of Henckel, Cramer, Gellert, Rinman, and Maquer. Bergmann (1871), to whom we owe the discovery of the fact that the presence or absence of graphite makes all the difference in the properties of wrought-iron, steel, and cast-iron, retained the phlogistic theory generally, although he considered that steel contains less phlogiston than wrought-iron. Professor Roberts pointed out that we are still repeating Bergman's question, "How does the graphite act" in producing the singular difference between hard and soft steel. The early experimenters who followed Bergman knew the importance of establishing the action of carbon in converting iron into steel, and Clouet, in 1796, followed by others in this country, converted soft iron into steel by heating it with the diamond. In these early experiments furnace gases had not been excluded, and it was urged that they might have converted the iron into steel without the intervention of the diamond. A past master of the Company of Cutlers, Mr. W. Haseltine Pepys, repeated in 1815, Clouet's experiment, under conditions which left no doubt as to the action of the diamond, for he employed electricity as a source of heat, and thus avoided the action of furnace gases altogether.

It was then shown that in soft, tempered, and hardened steel respectively, the carbon has a "distinct mode of existence," and the evidence as to whether carbon in steel is *combined* in the chemical sense, or is merely *dissolved*, was considered at length. The chemical evidence given by Berzelius, Karsten, Gurlt, Forquinon, and recently by Sir F. Abel, the distinguished chemist of the War Department, was then reviewed. With regard to the "solution" theory held by Vandermonde, Berthollet, and Monge in 1786, there is the recent and important calorimetric work of Troost and Hautefeuille, who showed that in white cast-iron, and probably in steel, the carbon is merely dissolved, a view which the lecturer adopted, as he did not consider it to be in any way in opposition to the fact established by Abel, that the carbon left by the slow action of a chromic acid solution is in the form of a definite carbide.

The various physical, as distinguished from the chemical, theories which had been set forth from the time of Réaumur, 1722, to that of Akerman, 1879, to account for the "intimacy of the relation" of carbon to iron in hardened as compared with soft steel, were then described. In recent years much importance had been attached to the physical evidence as to the peculiar constitution of steel, and it had been shown that there is a remarkable relation be-

tween the amount of carbon contained in different varieties of steel and their electrical resistance. The latest work, however, in this direction has been done by Prof. Hughes, and his very interesting experiments on the effect of torsion on wires of wrought-iron, soft and hard steel, through which a current is passed, was then described. The effect of hardening in oil on the tensile strength of steel of different degrees of carburization was then shown by the aid of curves, and it was incidentally pointed out that in the case of the variety of steel used for the manufacture of coinage dies a variation of 1-10th per cent. of carbon makes a great difference in the quality of the metal.

THE NEW STANDARD WIRE GAUGE FOR GREAT BRITAIN.—

Schedule.—Denominations of Standards.

Descriptive number.	Equivalents in parts of an inch.	Descriptive number.	Equivalents in parts of an inch.
No.	Inch.	No.	Inch.
7/0	.500	23	.024
6/0	.464	24	.022
5/0	.432	25	.020
4/0	.400	26	.018
3/0	.372	27	.0164
2/0	.348	28	.0148
0	.324	29	.0136
1	.300	30	.0124
2	.276	31	.0116
3	.252	32	.0108
4	.232	33	.0100
5	.212	34	.0092
6	.192	35	.0084
7	.176	36	.0076
8	.160	37	.0068
9	.144	38	.0060
10	.128	39	0052
11	.116	40	.0048
12	.104	41	.0044
13	.092	42	.0040
14	.080	43	.0036
15	.072	44	.0032
16	.064	45	.0028
17	.056	46	.0024
18	.048	47	.0020
19	.040	48	.0016
20	.036	49	.0012
21	.032	50	.0010
22	.028		

The *British Trade Journal* points out that on and after March 1st next no other wire gauge can therefore be used in trade in that country—that is to say, no contracts or dealings can be legally enforced which are made by any other sizes than those above given. Wire drawers and users of the Birmingham wire gauge would do well, therefore, to provide themselves with gauge plates corresponding to the above sizes.

ORDNANCE AND NAVAL.

NORDENFELT MACHINE GUNS.—On the invitation of Mr. Thorsten Nordenfelt, a large and influential company assembled at Dartford, on July 26, to witness the practiae carried out with the many different kinds of Nordenfelt machine guns, ranging from the single-barrelled rifle calibre weapon, up to the 2.2 in. single-barrelled 6-pounder gun. The practice was carried out at Mr. Nordenfelt's private range, at Dartford, and before the commencement Mr. Nordenfelt addressed a few words to the company explaining his views as to the use of machine guns afloat and ashore, and the nature of the mechanism of his various machine guns about to be fired.

The proceedings opened with the firing of the 12-barrelled rifle calibre gun, which is similar in all respects, but in the number of its barrels, to the 10-barrelled weapon which has been previously described and illustrated in this journal. Firing for rapidity without aiming, 590 shots were discharged from this gun in half a minute.

Then the single-barrelled rifle caliber gun, weighing only 13 lb., was similarly fired, with the result of 54 rounds in half a minute. This gun has been constructed as a cavalry weapon, or for use with mounted rifles, but we doubt whether a single-barrelled riffe caliber machine gun is ever likely to be adopted unless it be so exceedingly light that it might be practically introduced for one or other of the foregoing purposes. The 3-barrelled rifle caliber gun, which has a different and even more simple mechanism than either of the other rifle caliber guns exhibited, was next fired for rapidity with the result of 186 shots, or 62 volleys in the half-minute; this gun only weighs 56 lb., and its portability was shown by the ease with which two men carried it over rough ground on its tripod stand. This gun, in common with all the Nordenfelt guns of more than one barrel, has independent action of each barrel.

From the 5-barrelled gun, weighing 128 lb., 300 rounds were fired in the half-minute, and 10 volleys (50 shots) in 4½ seconds; this gun was then dismounted from its wheels and axle, and mounted on its tripod stand, which forms the trail when used with the wheels. The gun and stand were then each carried on poles by two men, to show the portability of this weapon.

Next came the 10-barrelled gun, from which 900 shots were fired in one minute; 100 rounds, with the automatic spreading gear in use, in 7 seconds; 200 rounds at 30 deg. elevation in 13 seconds; and 200 rounds at 30 deg. depression in 11 seconds. The improved scattering motion was here used, by which the bullets are separated 3 ft., so that the 10 shots of the volley cover a space of some 30 ft., and to throw the following volley to the right or left of the preceding one, it is only necessary to turn slightly the training wheel.

This concluded the firing of the small bore guns, from which 2,580 rounds were fired without a single jam, and by one man, thus proving the comparative ease with which these Nordenfelt machine guns, with the horizontal movement of their firing levers can be worked, and also the perfection of their mechanism.

The 2-barrelled 1-in. gun (185 lb. in weight), designed for the armament of torpedo boats, was then fired, at a distance of 50 yards, against a ⅛ in. steel plate, placed in front of a 1-inch

iron plate, both of which were penetrated by its steel shot. For rapidity of fire, 20 shots were discharged from this weapon in 6 seconds. A series of firing were then made with the 4-barrelled 1-in. gun, usually termed the "anti-torpedo-boat gun," with the following results: 8 single shots in 4 seconds, 12 shots (3 volleys) in 2 seconds, 100 shots (25 volleys) in 24 seconds.

The shell-gun practice was then commenced by the firing of the single-barrelled 1½-in. 2-pounder gun, weighing 3 cwt. At a distance of fifty yards the steel shot penetrated three 1-in. iron plates: and we were informed that at the Portsmouth machine shell gun trial in 1881, it penetrated a 1½-in. steel plate at 300 yards. Captain Lord C. Beresford, R.N., in his recent lecture on machine guns at the Royal United Service Institution, strongly advocated the adoption for the Navy of a shell gun of this nature, and we believe experiments for this purpose are about to be instituted; and it certainly appears to be a most suitable form of armament as judging from what we saw at Dartford, and from the Portsmouth trials of 1881, a 1½-in. shell gun can combine the features of lightness, rapidity of fire, penetrative power, considerable range and accuracy.—*Engineering.*

EARTH TORPEDOES IN SWITZERLAND.—The Geneva correspondent of the *Times* writes: Her von Zubowitz, inventor of the earth torpedoes which were tried the other day at Thun, is an Austrian hussar officer. He has led a very adventurous life, and served as a volunteer in wars in Spain, Albania, Montenegro, and Turkey. At Plevna he was one of Osman Pasha's aides-de-camp. There being no more fighting to be done just now, he has given his attention to perfecting facilities for future warfare. He has recently given a full explanation of the theory of his invention in the presence of the commission charged with its consideration, and of several superior officers of the Federal Army, among whom were General Herzog, Colonel Bleuler, and others who have seen active service in foreign armies. The Zubowitz torpedoes can be placed underground and used as substitutes for *fougasses;* they may be placed in a cart or wagon forming part of a barricade, and so arranged that the least movement of the vehicle will explode the engine. The trials at Thun are described as surprising. The torpedoes are composed of two boxes, one above the other, the first of which contains the charge, a sort of gelatine, while in the second is placed the exploding apparatus. By means of a conducting wire, cleverly hidden, the engine may be exploded at the most propitious moment at the will of a distant, and possibly an invisible, operator, or it may be arranged to go off by simple contact with a man or a horse. When the torpedo is put underground, at a very slight depth, its presence is concealed by stones, turf, or brushwood, according to the nature of the ground. The vibration of the air produced by the bursting of one of these truly infernal machines can be felt at a great distance, and the general effect is something prodigious. The most interesting experiment tried at Thun was the blowing up of two old caissons, which had been placed on a lorry. So violent was the explosion that not alone were the caissons and the lorry literally annihilated, but the spectators who watched the experiment from a "barrack of observation" at a distance of 200 metres were almost blinded by the cloud of dust raised by the blast. The opinion of the officers present at the trials was that the Zubowitz torpedoes will greatly facilitate defence, especially of a country like Switzerland, that possesses so many mountain passes and no strong places; but they cannot be made to supersede fortifications, and their adoption will solve only in part the problem of fortifying the territory of the Confederation, which has long been a burning question in Swiss military circles.

BOOK NOTICES.

PUBLICATIONS RECEIVED.

SELECTED PAPERS OF THE INSTITUTION OF CIVIL ENGINEERS.—A Method of Correcting Errors in the Observation of Angles of Plane Triangles. By Robert Manning, M. Inst C. E.

Apparatus for Solar Distillation. By Josiah Harding, M. Inst. C. E.

Tests of German Coals. By Dr. H. Bunte.

The Coal and Mineral Deposits of Indo-China. By Edmund Fuchs and E. Saladin.

Air-Compressor and Turbine. By Benjamin Frederic Wright, A. M. Inst. C. E.

Resistance on Railway Curves as an Element of Danger. By John Mackenzie, Assoc. M. Inst. C. E.

Cheap Gas for Motive-Power. By Joseph Emerson Dorson, A. M. Inst. C. E.

Abstracts from Foreign Transactions and Periodicals.

A TREATISE ON ELECTRICITY AND MAGNETISM. By E. Mascart, J. Joubert. Vol. I. London: Thomas De la Rue & Co.

This work when entire will comprise two parts. Only one is at present complete. The first volume is principally theoretical, and is a complete treatise in itself.

The authors have given special prominence to the views introduced into science by Faraday, and so largely developed by Clerk Maxwell on the consideration of lines of force.

The aim has been to prepare a book for physicists, and to simplify the demonstrations without sacrificing strictness of reasoning.

The translation from the original was made by Dr. Atkinson.

THE MODERN APPLICATIONS OF ELECTRICITY. Second Edition. Revised and Enlarged. By E. Hospitalier. New York: D. Appleton & Co.

Extensive as is the subject comprehended in the title to this work, the treatise doubtless fulfils the expectations roused by it. It is only twelve months since one volume quite satisfactorily covered the ground; now two royal octavo volumes are compactly filled with applications.

The subjects are presented in the following order:

Vol. I., Part I., Sources of Electricity.

Electric Batteries: Thermo-Electric Batteries; Electric Generators; Apparatus for Transforming Electricity.

Vol. I., Part II., Electric Lighting.

Arc Lamps; Electric Candles; Lighting by Incandescence; Applications of Electric Lighting.

Vol. II., Part I., Telephones and Microphones.

Tone Telephones; Speaking Telephones; Special Telephones; Applications of the Telephone.

Vol. II., Part II., Various Applications of Electricity.

Methanometers; Fire Alarms; Electric Water Gauges; Electrical Appliances for Navigation; Electrical Appliances for Meteorological Observations; Electro-Sorting; Electro-Metallurgy; Electrolytical Methods Applied to Manufacturing Processes; Electro-Medical Appliances; Preparation of Parabolic Mirrors by Centrifugal Force; Etching on Glass by Electricity; Electrical Appliances for Railway Communication; Bourdin's Plough for Laying Electric Cables; Siemens Galvanometers: Raimond Coulin's Photometer.

Vol. II., Part III., Electric Motors and Electric Transmission of Energy; The Distribution of Electricity.

ZOÖLOGICAL ATLASES. Invertebrates—Vertebrates. By D. M'Alpine. New York: The Century Co.

The two Atlases, one for each of the sections, are designed for students and teachers of Comparative Anatomy.

Sixteen large plates, with parts colored, are afforded in illustration of the Invertebrates. A page of text faces each plate.

Four plates are devoted to each of the subkingdoms, Protozoa, Annuloida, Annulosa and Mollusea.

The Atlas exhibiting Vertebrates contains twenty-four plates, of which nine are devoted to the anatomy of fishes, the skate and cod being selected as illustrations; four plates to reptilian structure, with the salamander and tortoise for examples; four plates to the anatomy of birds, the pigeon forming the example, and seven plates to mammalism anatomy, with the rabbit for the example.

The plates are large enough in most cases to be exhibited to classes of moderate size, and the distinct color is largely designed to aid such a purpose.

For teachers of Zoölogy who make use of the blackboard, these atlases afford invaluable suggestions.

THE ELASTICITY AND RESISTANCE OF THE MATERIALS OF ENGINEERING. By William H. Burr, C. E. New York: John Wiley & Sons.

The author of this new work is the Professor of Rational and Technical Mechanics in the foremost engineering school in the country. The lectures prepared for the classes at the Rensselaer Polytechnic Institute form the basis of the present work.

There are two distinct parts to the treatise. Part I., Rational: presents the General Theory of Elasticity in Amorphous Solid Bodies—Thick, Hollow Cylinders and Spheres and Torsion—The Energy of Elasticity, and—Theory of Flexure.

Part II., Technical: Tension—Compression—Long Columns—Shearing and Torsion—Bending or Flexure—Connections—Miscellaneous Problems—Working Stresses and Safety Factors—The Fatigue of Metals—The Flow of Solids.

The first or analytical part is designed chiefly for students. Part II. exhibits the mathematical results subjected to the test of experiments.

The tables of this part, for which the work will be most widely sought by engineers, possess a value not usually belonging to compilations of this character, inasmuch as they have been prepared by a skilled instructor of engineering.

From the author's position and reputation as a writer on engineering subjects, it is safe to predict a wide demand for the book.

ELEMENTS OF SURVEYING AND LEVELING. By Charles Davis, LL.D. Revised by J. Howard Van Amringe, A. M., Ph. D. New York and Chicago: A. S. Barnes & Co.

If there is a better work than this on surveying, either for students or surveyors, our attention has not been called to it. The preceding edition is probably the best known work on the subject in this country. The present work is offered as a revision and enlargement suited to the newer demands of the engineering profession.

The editor, Dr. Van Amringe, is in a position to become fully aware of the wants to be satisfied, and eminently fitted to present the new subjects in a clear and logical manner. Every section has been carefully revised. Among the newly written chapters may be noted Trigonometrical Surveying, Topographical Surveying, and Mining Surveying. The more important revisions of the old matter relate to new methods of computing areas of land, volumes of earthwork, and the location of compound curves.

The Adjustment of the Transit, the Determination of the Meridian, and the Survey of Public Lands, are subjects materially extended.

An Appendix contains descriptions of the Solar Compass and Sextant, and of the method of their use.

The number of illustrations has been largely increased, and the typography exhibits the excellencies which distinguished the former editions.

DIXON'S MACHINISTS AND ENGINEER'S CALCULATOR.—The Machinists and Engineers' Practical Calculator; a compilation of useful rules and problems arithmetically solved, together with general information applicable to shop-tools, mill gearing, pulleys and shafts, steam boilers and engines; embracing valuable tables and instruction in screw cutting, valve and link-motion, etc., etc. By D. B. Dixon.

New York: D. Van Nostrand, Publisher, 27 Warren Street.

Of books for machinists and engineers there are no end, most of them professing to afford information upon points not generally known, and to give simple rules for arriving at the proportions of machinery and steam apparatus in general. Unfortunately, the compilers of these works address a comparatively small class in the community of workers, for they have, for the most part, locked up the knowledge they possess in algebraic formulæ, and advanced arithmetical problems, with the result of disappointing the very persons who most need the information. The mathematicians in any community are a small proportion of the whole, and among working men, in particular, there are very few who have any more than rudimentary knowledge of the first four rules of arithmetic. If they could make these available, and solve some rules by their aid, they would be encouraged to seek further, and in due time become expert with figures.

It is just in this respect that the average pocket-book for engineers and machinists disappoints the class who have a special need of it.

We are glad to find, in the work under notice, that the author is fully aware of the defects in pocket-books generally, for the use of those who have had limited educations, and he has so simplified standard rules that any young man, who can multiply and subtract, can avail himself of a great deal in mechanical engineering, which he has hitherto been debarred from. Moreover, the author instructs in mathematics; avoiding the jargon of schools, and the trade terms of text-book makers; he leads the willing pupil into a thorough knowledge of square and cube root, involution, evolution, and mensuration. Before he is aware that he is learning something the mysteries vanish, and the student finds that, by the aid of a competent teacher, who knows his needs, mathematics, so far as we have noted, is quite within his capacity. Many men have fancied that they were in some way mentally deficient, as regards the solution of problems, and have wondered why matters, which are simple to others, seemed so difficult to them. The trouble lies, in a majority of cases, with the methods by which they have attempted to learn, and not with their mental constitutions.

For example, in one book for engineers and machinists, we find the following rule for the size of a shaft to resist torsion, or twisting strains:

"The diameter of a cast iron shaft to transmit a certain horse-power, H, is to be multiplied by 400 and divided by the number of revolutions per minute, n, then extract the third root of the quotient; this gives the diameter in inches." The formula is

$$\frac{\sqrt[3]{400 \times H}}{n}.$$

This is simple enough to those who know all about it; but to the man who is building a water-wheel, and has not had the pleasure of the acquaintance of that mysterious zig-zag in front, the knowledge he seeks is as far off as ever. If he had Dixon's Pocket-Book, he would turn to it and find, under the head of torsion, this rule, p. 166:

"*To determine the diameter required for a given torsional stress.*

Rule. Multiply the twisting force in pounds by the length of the crank in feet, divide by 120, and the cube root of the product will be the diameter in inches."

When the millwright or working engineer sees this, he says: "Here is that terrible cube root again," but, as he has previously read the contents of the work mentioned, he finds that cube root and how to extract it is all laid down plain before him.

This wonderful process, he sees, is nothing but the first four rules of arithmetic after all, used in a certain sequence; and before he is aware of it he has learned it. We use this term—"before he is aware of it"—advisedly, because Mr. Dixon's methods of induction (leading up to a subject) are so clear that any one can understand and practice them.

We have been thus diffuse in our notice of Dixon's Pocket-book for the reason that it opens a new field to the working mechanic and engiheer. It is not only couched in simple arithmetical practice, as to its explanations, but it also instructs in the higher mathematical branches. In a sense, it might be called a mechanics' arithmetic, for, in combination with the various tables and rules for proportions of steam-boilers and engines, gears, screw-cutting, etc., etc., it is an arithmetic. For the class to whom it is chiefly addressed, it is a most valuable work and the most complete of its kind. When a mechanic has mastered it, he will find it a key to many other more advanced works and will derive many times its cost in knowledge he would otherwise acquire either very slowly or not at all. The price is $2.00, and we think all who aspire to be more than mere hewers of wood and drawers of water will send for a copy at once.—*The Mechanical Engineer.*

MISCELLANEOUS.

At a recent meeting of the Paris Academy of Sciences M. Loewy explained his new method for determining at any moment the relative position of the instrumental equator in relation to the real equator. This method is analogous to that already given for right ascensions, being founded on the observation of the stars near the pole, and on the variations in the relations of the co-ordinates due to the deflection of the instrument. M. Leowy demonstrates mathematically that his plan combines all the theoreticel and practical conditions required for the complete solution of the problem. It is based on the theorem here demonstrated that when the track described by a star in apparent distance from the pole coincides with its distance in relation to the instrumental plane, the angle may be exactly determined which is formed by the terrestial axis with the line of the instrumental poles, by means of the variation observed between the apparent polar

distance and the distance in relation to the instrumental plane. The method is independent of any possible variations in the state of the instrument during a period of twelve hours, and it excludes the cause of systematic error due to refraction. It is, moreover, capable of extreme accuracy, which, by multiplying the points, may be carried so far as desirable.—*Engineer.*

ROYAL TESTING ESTABLISHMENT, BERLIN.—A new journal has recently made its appearance which promises exceptionally well. It is devoted to information on testing materials, forms the official organ of the royal testing establishments in connection with the Berlin Polytechnic, and is edited by Dr. H. Wedding, whose name is a guarantee for the high standing of the new journal. The first number, which has just reached us, is a quarto journal of forty-eight pages containing a variety of information on the subject of tests of material, regulations for the Berlin laboratories for mechanical and chemical tests, the tests of building materials, &c. An elaborate article by Dr. Bohme, the assisant manager of the institution, deals with the most suitable form for the ends of test bars, and in it are illustrated some very ingenious ball sockets for holding the test-piece, the latter having only a straight collar at the end if round, or being widened if flat. Professor Finkenir, the manager, contributes an article on investigations of pig iron, dephosphorized by the basic process, while some exhaustive tests of cement and cement concretes, made by Dr. Bohme with a view of comparing German and Russian standards, are given in full. The journal has probably not a very wide field, but in the interest of scientific research, we trust it will prosper. Published by Julius Springer, of Berlin, it is quite up to the best standard of journals in typography and illustrations. The latter are excellent engravings on stone. The title of the journal is "Mittheilungen aus den konigl. Technischen Versuchsan-Stalton zu Berlin."

SOUTH AMERICAN TIMBER.—Some investigations by M. Thanneur show that South America is rich in woods for engineering purposes. The yandubay is exceedingly hard and durable; the couroupay is also very hard and rich in tannin. The quebracho is, however, more interesting than any, and grows abundantly in the forests of La Plata and Brazil. It resembles oak in the trunk, and is used for railway sleepers, telegraph poles, piles, and so on. It is heavier than water, its specific gravity varying between 1.203 and 1.333. The color at first is reddish like mahogany but grows darker with time. Being rich in tannin it is employed for tanning leather in Brazil, and has recently been introduced for that purpose into France. A mixture of one-third of powdered quebracho and two-thirds of ordinary tan gives good results.

A DESCRIPTION of the hektograph or gelatine pad now so extensively used for reproducing copies of letters is given by the *Glassware Reporter* as follows:—"An old French method of printing and transferring was to cast a sheet of glue, ¼in. thick, diluted, while warm, to such a consistence that when cool it was perfectly flexible and pliable as leather. The impression was first taken from the copper plate upon this sheet of glue, and then transferred to the article requiring decorating. The glue could be applied to the ware two or three times before it became necessary to take a fresh impression from the plate. Black printing in the Staffordshire potteries, was at one time done by a similar process, the gelatine bats being cast on dish bottoms, and then cut to the size required for the patterns. But this printing from bats has now fallen into disuse."

SOME varieties of South American wood have been described by M. Thanneur which seem likely to become valuable for engineering purposes. The yandubay is exceedingly hard and very durable. The couroupay is also very hard and very rich in tannin. It bears some resemblance to the quebracho, which is perhaps the most interesting of all and the most used. It is very abundant in Brazil and La Plata. Its diameter varies within the same limits as that of the oak, but the trunk is shorter. It is used for railway sleepers, telegraphic poles, piles, &c. It is very durable, especially when well seasoned. Its specific gravity is from 1.203 to 1.333. Its color is reddish, like mahogany, but it becomes darker in time. On account of its hardness it is difficult to work, and it cannot be readily cut with an axe, but it has been introduced into France on account of its richness in tannin.

PHOSPHOR-COPPER.—Mr G. Otto, of Darmstadt, has brought out a new combination of phosphorus, and copper, called phosphor-copper containing fifteen per cent. of phosphorus and intended for admixture with other metals. The favorable influence of phosphorus on copper and copper alloys is owing to its energetic reducing action on the oxygen which they contain, the result being extreme closeness of grain, combined with great elasticity. The new material may be added to copper alloys of all descriptions without any admixture of tin, such as brass, German silver, &c.; it can also be used in refining copper. It is supplied in tablets weighing about 2lb. each, 15lb. to 20lb. being sufficient for the production of one ton of phosphor-bronze, and only increasing the cost from one to three shillings per cwt. Most of the Continental government works have used phosphor-copper for a considerable time with most successful results, and it is now being introduced into this country by Mr. G. Hartmann, of 16, Great St. Helens, E. C. To produce homogeneity in castings, both of this material and also of other metals and alloys, the same inventor has devised a stirrer or agitator, which consists of a handle having at its lower extremity a dovetailed groove, into which is inserted a piece of chalk, marble or other mineral capable of giving off carbonic acid gas. When the metal is molten it is stirred with this instrument and large quantities of gas are liberated with great force, the result being that a thorough admixture of the metal is produced. It is claimed that all the gases previously present are expelled, and that no trace of the carbonic acid remains, while the latter accumulating on the surface, prevents the absorption of oxygen from the atmosphere.

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